

ISSN 1000-9620



海洋通报

Marine Science Bulletin

NATIONAL MARINE DATD AND
INFORMATION SERVICE OF CHINA

2014

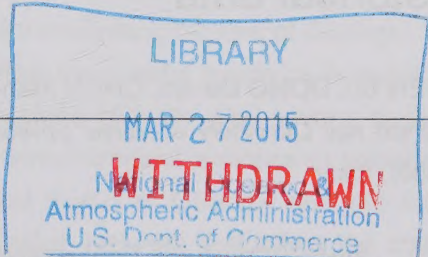
Volume 16
Number 1



LIBRARY
Pacific Islands Fisheries Science Center
NOAA Fisheries
Honolulu, Hawai'i

MARINE SCIENCE BULLETIN

Vol. 16 No. 1 May 2014



CONTENTS

Analysis on the causes of tropical cyclones and their disasters affecting on Guangxi coast
based on historical data CHEN Bo et al. (02)

Statistical and cause analysis of storm surges along Tianjin coast during the past 20 years
..... LI Xi-bin et al. (15)

Island instantaneous coastline extraction based on the characteristics of regional
statistics of multispectral remote sensing image WANG Feng et al. (25)

Research on the evaluation of marine function zoning and its practice in China
..... HUANG Nan-yan et al. (38)

Using factor analysis on the comprehensive evaluation of oil pollution
in the Haihe river basin DAI Yuan-yuan et al. (51)

Source analysis and ecological risk assessment for heavy metals in the sediments
of Yangshan Deepwater Harbor in autumn and winter YE Ran et al. (59)

Study on acid-volatile sulfide (AVS), simultaneously extracted metals (SEM) and its toxic
effect on the organism in intertidal sediments of Donghai Island, Zhanjing
.....ZHANG Ji-baio et al. (73)

Research on the rationality of artificial reef layout of Dashentang
..... WANG Hong et al. (89)

Analysis on causes of tropical cyclones and their disasters affecting on Guangxi coast based on historical data

CHEN Bo, DONG De-xin, CHEN Xian-yun, LIU Hui, QIU Shao-fang

Guangxi Key Laboratory of Marine Environmental Science, Guangxi Academy of Sciences, Nanning 530007, China

Abstract: The tropical cyclone that lands or passes through Guangxi coast is a serious natural disaster, which brings about strong winds, heavy rains, storm surges and other disasters causing severe damage of property or casualties in the coastal region every year. By counting and analyzing the tropical cyclones affecting Guangxi coast from 1950 to 2012, we find that the annual number of tropical cyclones changes significantly, and the maximum value can be up to 9, whereas the minimum value is 0 in some year. The regularity of seasonal distribution of tropical cyclones is obvious, and the peak period is in July, August and September every year, followed by June and October. Most of tropical cyclones come from the east of Philippines. After entering the South China Sea and passing through Hainan province and Leizhou Peninsula, they landed on Guangxi coast once again and caused the mean of peak surge reaching 111.2 cm, which is 2.6 times of non-landing typhoon. The formation of storm surge disaster is directly related to the severe typhoon weather systems, diurnal spring tide and discharge of river flood. Severe typhoons generate huge waves and rainfall, which lead to the rise of water level at the estuary, and would result in significant increasing water when stacking up with the storm surge, and cause huge tidal disaster.

Keywords: Guangxi coast; tropical cyclone; disaster causation; impact analysis

The tropical cyclone occurs in the tropical or sub-tropical low-pressure vortex over the sea surface, and is a powerful and complex tropical weather system. Tropical cyclones usually form on the sea surface in the tropical regions away from the equator by 3 to 5 latitudes (e.g. Northwest Pacific, North Atlantic, Indian Ocean), whose movements are mainly influenced by the Coriolis force, and other large-scale weather systems, and eventually dissipate at sea, or degenerate to temperate zone cyclones, or dissipate in the inland after landing. With the arrival of tropical cyclone, big wind, heavy rain, storm surge can cause serious property damage or personal injury. Therefore, the tropical cyclone is a

serious natural disaster.

The coastal region of Guangxi is located in the low-latitude area, and subject to the subtropical monsoon climate. On average, there are five tropical cyclones affecting the coastal region of Guangxi each year, while the maximal number of tropical cyclones can reach nine, leading to different damages to the coastal and inland regions of Guangxi. This study combines the fact that the tropical cyclones affect the coastal region of Guangxi and the results that the researchers in Guangxi have obtained over the past several decades as well as relevant literatures and parts of data on annual tropical cyclones to statistically analyze the tropical cyclones that affect the coastal region of Guangxi and the cause inflicted disasters. In the following analysis, the tropical cyclones that affect the coastal region of Guangxi are referenced to the tropical cyclones whose center enters the region in the north of 18° N and in the west of 112° E.

1 Distribution of tropical cyclones affecting the coastal region of Guangxi over Time course

1.1 Annual distribution

Tab. 1 lists the number of tropical cyclones that affected the coastal region of Guangxi from 1950 to 2012 (Wu, 1998; Kong, 1997; Li et al., 2009; Li et al., 2004; Liang et al., 2008; Zhang et al., 2000). Several characteristics can be found in Tab. 1.

(1) For 63 years from 1950 to 2012, there were 305 tropical cyclones that affected the coastal region of Guangxi, and there were 4.84 tropical cyclones per year on average. Of those tropical cyclones, from 1970 to 1979, there were the most tropical cyclones with an average of 5.9 tropical cyclones per year, whereas the 10 years from 2001 to 2010 account the least with an average of 3.7 tropical cyclones per year. Yet, the maximal number of tropical cyclones can reach 9 in a single year, and the minimal number of tropical cyclones can as few as zero. Therefore, the number of tropical cyclones fluctuates significantly across years.

(2) For these 63 years, the interval between tropical cyclones with maximal impact was about 20 years, i.e. three periods of early 1950s, early 1970s and early 1990s. However, the interval between tropical cyclones with the minimal impact occurred early 1980s and the 10 years after 2000, but there was no clear time pattern for tropical cyclones with the minimal impact.

(3) Of these 63 years, 34 years are marked with the number of tropical cyclones affecting the coastal region of Guangxi larger than 5, accounting for about 54% of tropical

cyclones; 23 years with 3 or 4, accounting above 36%; 6 years with 2 or less than 2, accounting for 9.5%; and 6 years with 8 or 9, accounting for 9.5%. The tropical cyclones affected the coastal region of Guangxi most frequently in 1952, 1974 and 1994, of which there were 9 tropical cyclones each year, while there was no tropical cyclone affecting the coastal region of Guangxi in 2004.

**Tab. 1 Tropical cyclones affecting Guangxi coast north of 18° N
and west of 112° E from 1950 to 2012**

Year	Number	Year	Number	Year	Number	Year	Number	Year	Number
1950	5	1963	6	1976	5	1989	4	2002	4
1951	6	1964	6	1977	5	1990	4	2003	5
1952	9	1965	6	1978	5	1991	4	2004	0
1953	7	1966	4	1979	4	1992	5	2005	3
1954	6	1967	8	1980	5	1993	7	2006	6
1955	3	1968	5	1981	7	1994	9	2007	3
1956	6	1969	2	1982	3	1995	8	2008	4
1857	4	1970	5	1983	4	1996	6	2009	4
1958	6	1971	8	1984	4	1997	1	2010	3
1959	3	1972	4	1985	7	1998	4	2011	3
1960	6	1973	7	1986	5	1999	2	2012	3
1961	7	1974	9	1987	1	2000	1	-	-
1962	4	1975	7	1988	3	2001	5	-	-

1.2 Seasonal distribution

According to the data from 1950 to 2012, the tropical cyclones that affected the coastal region of Guangxi were more concentrated in the summer. Typhoons and tropical depressions began in May and end in December, so there were no influences from typhoons and tropical depressions from January to April. However, the period from July to September was the typhoon season, and tropical cyclones over these three months accounted for 73% of tropical cyclones in the whole year. Still, in May and November, there were the least number of tropical cyclones, which accounted for 3% to 4% of tropical cyclones in the whole year. On the other hand, tropical depressions appeared most frequently in August and September accounting for 59% of tropical depressions in the

whole year.

According to the data on tropical cyclones that affected the coastal region of Guangxi from 1949 to 1998 (Wu, 1998), there were always tropical cyclones affecting the coastal region of Guangxi from May to December for these 50 years. Of these tropical cyclones, the tropical cyclone No. 7102 was the earliest one beginning on May 3rd, while the tropical cyclone No. 7427 was the latest one beginning on December 1st. There were 37 tropical cyclones that affected the coastal region of Guangxi in May and June accounting for 14.2%, 34 tropical cyclones from October to December accounting for 13.0%, while the rest 72.8% of tropical cyclones occurred from July to September. Although the data covered different years, the distribution patterns of tropical cyclones were similar and clear.

2 Influence of tropical cyclones on coastal region of Guangxi and their patterns

2.1 Tropical cyclones entering coastal region of Guangxi

Tropical cyclones form in the intertropical convergence zone (ITCZ), of which the north side is strong subtropical high-pressure. The movement of tropical cyclones is mainly led by partly eastward air current in the south side of subtropical high-pressure. This type of tropical cyclones often lands on the southeast coast of China as well as the coastal areas in Vietnam. The tropical cyclones that enter the coastal region of Guangxi form largely in the western part of the North Pacific, and main areas for their intensive development are the sea surface east to the Philippines and the South China Sea. Formation source of tropical cyclones varies with the seasons: in the very summer time, they mainly develop in the northern part of the South China Sea, while in autumn and spring, they generally develop on the sea surface east to Philippines, as well as the sea surface near Spratly Islands in the middle and south parts of the South China Sea.

The pathway, through which tropical storms move, is very complex, and is generally governed by the internal strength and structure of tropical cyclones, and other factors, but is also governed by the air pressure system, controlling the air current and the Coriolis force in surrounding areas, and so on. In history shows that the pathway, through which the tropical storms entered into the coastal region of Guangxi, was different one from the other, however, before entering the coastal region of Guangxi, tropical storms landed in the western part of Guangdong Province, and Hainan Province in most cases, and then entered, landed and influenced the coastal region of Guangxi (Chen et al., 2000; Zhang and Wen, 2000; Lin, 1994). The pathway, through which the tropical storm center passes near the coastal region of Guangxi can be classified into three types.

(1) Northwest Type: After entering the South China Sea, tropical storms firstly land between Wanning County, Hainan Province and Leizhou Peninsula, Guangdong Province, then enter into the Beibu Gulf, and move northwestward in the Beibu Gulf, and land in the region north of 20° N again. The tropical cyclones, which impact the coastal region of Guangxi, normally belong to this type.

(2) Westbound Type: After entering the South China Sea, tropical storms pass over either the Qiongzhou Strait or Leizhou Peninsula, and move towards the west, and land in the region north of 20° N.

(3) Northbound Type: After entering the South China Sea, tropical storms move towards either northwest or west at first, and then turn to the north, and land the coastal region west to the Leizhou Peninsula.

Of tropical storms along one of these three pathways into the coastal region of Guangxi, the Northwest Type appears most frequently, followed by the Westbound Type, while the Northbound Type appears the least frequently. In analyzing the pathways through which tropical cyclones influenced and landed the coastal region of Guangxi from 1965 to 2010, we found that there were about 90 tropical cyclones affecting and landing the coastal region of Guangxi over these 40-plus years, and 15 tropical cyclones came from the sea surface east to Philippines into the South China Sea, and then passed through Hainan Province and Leizhou Peninsula and directly landed the coastal region of Guangxi (Figure 1). The tropical cyclones, which directly landed in the coastal region of Guangxi, led the average storm surge increase to 111.2 cm, which is 2.6 times higher than the storm surge without the landing of tropical cyclone. Because this type of tropical cyclones has a longer duration and a larger precipitation, it is often at the time when the storm surge increases while astronomical high tide comes, resulting in two tides to be superimposed, and resulting in huge storm surge disasters.

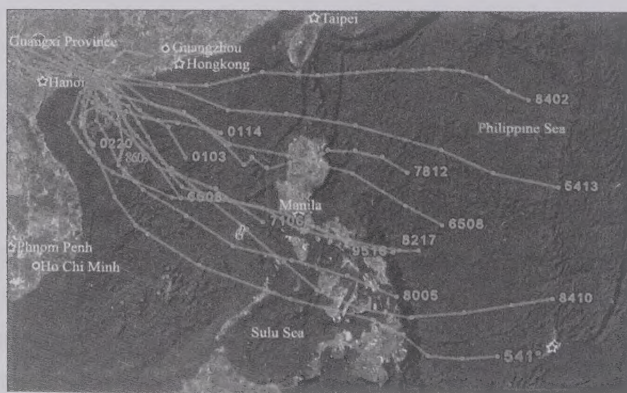


Fig. 1 Pathways of typhoons landing the coastal region of Guangxi from 1965 to 2010

2.2 Storm surge disasters caused by tropical cyclones

As mentioned above, the tropical cyclone is a natural disaster. Once it is formed, unfavorable weather and sea situations will appear with the fierce wind, heavy rain and storm surge, which can influence the area from a few hundred kilometers (or more) to the tens of kilometers, leading huge damages. The factors for which the tropical cyclones lead to huge disasters include the fierce wind, heavy rain and storm surge, which can bring about severe property damage or human casualties. In the following, the analysis on the storm surge and damage caused by tropical cyclones is made.

2.2.1 The maximal increase in the storm surge

Storm surge is the abnormal rise of sea level due to strong atmospheric disturbances, for example, strong winds or sudden changes in the air pressure, (Feng, 1982). The coastal region of Guangxi is one of regions that are frequently affected by storm surges. According to historical data, on average, 2 or 3 typhoons land or affect the coastal region of Guangxi each year, and to the maximum, 5 typhoons in 1973. Most of the typhoons were accompanied by the occurrence of storm surges. From 1965 to 2010, typhoons' landing and influence on the coastal region of Guangxi led the maximum storm surge increase 0.5 m - 1.0 m for 18 times, 1 m for 11 times, and more than 2 m for three times. Among them, Typhoon No. 7109 caused the storm surge beyond 2.33 m in Port Tieshan on June 2, 1971. Typhoon Sarah No. 8303 on July 18, 1983 in Port Fangcheng station and Typhoon Sally No. 9615 on September 9, 1996 in Port Tieshan, Qinzhou and Port Fangcheng stations caused the maximum storm surge increase more than 2 m. Typhoon Krovanh No. 0312 on August 24, 2003 caused the maximum storm surge increase 1.79 m. A maximum increase in storm surge occurs almost every ten years (Fig. 2).

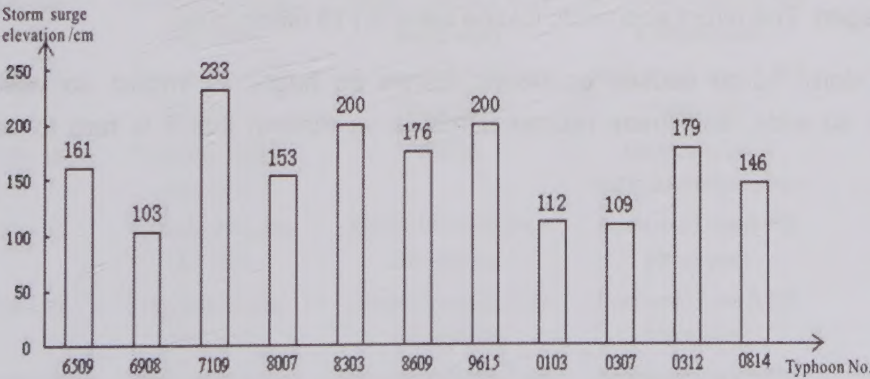


Fig. 2 Storm surges beyond 1 m in major ports in the coastal region of Guangxi from 1965 to 2010

2.2.2 Damages caused by storm surge

Storm surges induced by tropical cyclones lead to heavy property losses and human casualties. Due to the data limitation, Tab. 2 only shows the damages from 1986 to 2012 in the coastal region of Guangxi by the storm surge (Nong et al., 2009; State Oceanic Administration, 2013; Guangxi Zhuang Autonomous Region Oceanic Administration, 2013; Zeng, 1996; Chen, 2013). In recent 20-plus years, storm surge caused direct economic losses up to 11.699 5 billions yuan, affected 10.537 3 millions of people, with 102 deaths (excluding missing), damaged 610 thousand hm^2 in agriculture and cultivation fields, destroyed 162.9 thousand houses, ruined 476.57 km coastal engineering, and damaged 1613 vessels in the coastal region of Guangxi (Tab. 2). In these damages, Guangxi suffered the 15th storm surge on Sep. 9, 1996, and waves as high as 3 m broke 372 places with the total length of 48.28 km in Beihai's seawall, leading to the huge influx of seawater. A county and three districts belonging to Beihai city were affected. The affected population reached 1.114 8 million people including 61 deaths, 88 people missing, 34,700 houses collapsed, 1 099 vessels damaged, 173 vessels sank, and direct economic losses are 2.555 billion yuan. Moreover, in Qinzhou City, 20,000 houses collapsed, and 2 people died, and 300 m seawalls destroyed. Strong tropical storm Durian (No. 3 in 2001) directly attacked Beihai, where heavy rains fell from 8:00 A.M. on June 26 to 7:30 A.M. on June 27, and daily rainfall was 425 mm. This storm resulted in the destruction of most of the roads in the urban areas, street and houses flooded, and the storm was so strong that can be considered to once a century. A half million people in the city were affected, with 150,000 people flooded; the seawall was broken at 30 places with a length of 200 m; 150 landslides occurred in the riverbank and embankment; 16 water weirs and water gate were destroyed; the flood filled 1,130 hm^2 fish and shrimp cultivating ponds, of which 63.33 hm^2 shrimp cultivating ponds were washed away; 14,600 hm^2 crop field was inundated; 548 km roads were damaged. The direct economic losses were 1.713 billion yuan.

The storm surge causes economic losses so huge, its impact so vast, and its destruction so wide, and these related numbers so thrilling that it is rare to see similar losses.

Tab. 2 Loss and damage led by the storm surge of major typhoons in the coastal region of Guangxi from 1986 to 2012

Time	Name of Typhoon	Affected Areas	Economic Losses and Human Casualties	Maximum storm surge / cm
1986-07: 21 - 22	Typhoon Sarah No. 8609	Beihai, Qinzhou	Economic Loss 0.39 billion yuan, 37 deaths	176
1992-06: 28 - 29	Typhoon Deanna No 9204	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.077 billion yuan, 1 death	90
1996-09: 09 - 10	Typhoon Sally No. 9615	Beihai, Qinzhou, Port Fangcheng	Economic Loss 2.555 billion yuan, 63 deaths	200
2001-07: 02 - 06	Typhoon Durian No 0103	Beihai, Qinzhou, Port Fangcheng	Economic Loss 1.712 93 billion yuan	112
2002-09: 27 - 28	Typhoon Megkhla No. 0220	Beihai, Qinzhou	Economic Loss 0.293 1 billion yuan	58
2003-07: 19 - 21	Typhoon Imbudo No. 0307	Qinzhou, Port Fangcheng	Economic Loss 1. 882 billion yuan	109
2003-08: 24 - 25	Typhoon Krovanh No. 0312	Beihai, Qinzhou, Port Fangcheng	Economic Loss 1.236 1 billion yuan	179
2005-09: 26 - 27	Typhoon Damrey No. 0518	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.058 2 billion yuan	89
2006-08: 02 - 03	Typhoon Prapiroon No. 0606	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.7037 billion yuan, 1 death	-
2007-07: 02 - 06	Typhoon Torsi No. 0703	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.0546 billion yuan	98
2007-09: 23 - 26	Typhoon Francisco No. 0714	Port Fangcheng	Economic Loss 0.2142 billion yuan	51
2007-10: 01 - 05	Typhoon Lekima No. 0715	Beihai	Economic Loss 0.016 9 billion yuan	84
2008-08: 05 - 09	Typhoon Kammuri No. 0809	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.175 8 billion yuan	96
2008-09: 23 - 25	Typhoon Hagupit No. 0814	Beihai, Qinzhou, Port Fangcheng	Economic Loss 1.397 0 billion yuan	146
2009-09: 15 - 16	Typhoon Koppu No. 0915	Beihai	Economic Loss 0.010 423 billion yuan	84
2010-07: 22 - 23	Typhoon Chanthu No. 1003	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.153 billion yuan	52
2011-09: 29 - 30	Typhoon Neast No. 1117	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.115 billion yuan	72
2012-08: 17 - 18	Typhoon Kai-Tak No. 1213	Beihai, Qinzhou, Port Fangcheng	Economic Loss 0.465 billion yuan	106

2.3 Reasons for storm surge disasters

The main reasons for storm surge disaster would include the following aspects.

2.3.1 Weather systems

Formation of storm surges has direct relationship with changes in weather systems. High temperatures, high humidity, and other suitable meteorological conditions on the tropical ocean surface (also called tropical cyclones) are key factors in the formation of storm surge. When the maximum wind speed of tropical cyclone reached 12 degree (32.7 m/s), a typhoon weather is created, and at this time, the typhoon will generate huge waves on the sea surface. For example, Typhoon Hagupit (international designation: 0814) initially formed on the ocean surface east to Philippines at 20:00 on September 19, 2008 (Zhou, 2009), and it strengthened into a typhoon at 14:00 on September 21. At noon on September 22, it strengthened as a strong typhoon, and then it entered into the northeastern South China Sea before 23:00. At 6:45 on September 24, it landed the coastal region of Chen Village Town, Dianbai County, Maoming City, Guangdong Province with the central pressure 950 hPa, and the average wind speed around the typhoon center was 48 m/s (15 degree), and the maximum gust was 65 m/s (17 degree). Around 12:00, it moved from Lianjiang County, Zhanjiang City, Guangdong Province into Guangxi Province through Yulin, Beihai, Qinzhou, Port Fangcheng and other places, and then continued moving to the northwest. It weakened into a strong tropical storm at 14:00 and into a tropical storm at 17:00. After 2:00 on September 25, it further weakened into a tropical depression, and at 8:00 on September 25, it moved out of Guangxi into northern Vietnam around Cao Bằng, stayed in northern Vietnam until September 26. Under Hagupit's influence, the waves as high as 1 to 2 m (effective wave height) appeared in the coastal region of Guangxi, and the measured wave height around Weizhou Island reached 4.5 m. Storm surges appeared in each port to varying degrees, of which, storm surge at Port Beihai, Qinzhou, Port Fangcheng, increased about 0.79 m, 0.59 m and 0.89 m, respectively, while storm surge increased up to 1.46 m in Port Tieshan. Typhoon Hagupit has been the strongest typhoon that entered into Guangxi Province since 1971, and has also been the typhoon that affected Guangxi Province for longest period of time, the largest scale and heaviest rainfall since establishing meteorological records, and caused huge economic losses and heavy casualties.

2.3.2 Superposition of diurnal spring tide, storm surge and huge waves

Whether or not a storm surge can cause disasters is largely dependent on the fact if the maximum storm surge and an astronomical tide are superimposed, especially

superimposed with the astronomical spring tide climax. We analyzed the data from 1986 to 2010 that 16 storm surges increased up to 0.5 m over these 25 years, and each maximal storm surge coincided with the diurnal spring tide in the Beibu Gulf. For example, the time from July 21 to July 22, 1986 coincided with the lunar diurnal spring tide from June 16 to June 17, thus Typhoon Sarah No. 8609 led the storm surge to increase up to 1.76 m; the time from September 9 to September 10, 1996 coincided with the lunar diurnal spring tide from July 28 to 29 July, thus Typhoon Sally No. 9615 led the storm surge to increase up to more than 2 m; the time from August 24 to August 25, 2003 coincided with the lunar diurnal spring tide from 28 July to 29 July, thus Typhoon Krovanh No. 0312 led the storm surge to increase up to 1.79 m; the time from September 23 to September 25, 2008 coincided with the lunar diurnal spring tide from August 26 to August 27, thus Typhoon Hagupit No. 0814 led the storm surge to increase over 1.46 m. The superposition of storm surge and diurnal spring tide lead unusually high tide level, under the influence of strong typhoon weather systems, resulting in huge waves and destructive force, especially for the embankment, moisture-proof gates and other hydraulic structures as well as severe damage to vessels. And all these make disaster losses increase. Therefore, the economic losses caused by these several storm surges have reached 1.0 billion yuan.

2.3.3 Encountering of discharged river floods and storm surge

Almost all the time when typhoons influence or land the coastal region of Guangxi, they accompany with the heavy rain or very heavy rainfall. On the other hand, every large-scale, high-intensity rainfall will enable the water level to increase in rivers that flow into sea in the coastal region of Guangxi. As the flood goes down along the river to the sea, the storm surge makes water go up adversely along the river, thus the two meet together unexpectedly, causing the river to raise the water level. Both river water and seawater together spread into the farmland, villages, salt factories and enterprises, all of which make severe losses to human life and property of local people and local economy. For example, at 6:45 on September 24, 2008, typhoon Hagupit No. 0814 landed the coastal area in Maoming City, Guangdong Province (Liang, 2009), and it entered Guangxi Province at 12:00 and moved gradually westward. Its rains covered the entire coastal region of Guangxi. From 08:00 on September 24 to 08:00 on September 27, the cumulative rainfall was 500 mm in six towns in five counties (districts), of which, rainfall was more than 700 mm in two towns, i.e. 767.2 mm in Naliang Town, Fangcheng District, Port Fangcheng City, and 721.9 mm in Dongzhong Town, Fangcheng District. Also, the average rainfall was 300 to 400 mm in 39 coastal towns. The heavy rain lasted 4 days, with the largest scope, the strongest intensity, and the longest duration. When the flood discharged into the sea through 23 rivers with various size estuaries along Guangxi coastal line and met with storm

surge, the water level dramatically swelled, leading the water in coastal cities, Port Tieshan, Beihai, Qinzhou, Port Fangcheng, Port Pearl and other harbors to increase 146 cm at the maximum. This storm surge caused direct economic losses of 1.397 billion yuan in Guangxi coastal line cities, Port Fangcheng, Qinzhou and Beihai.

3 Conclusions

(1) The tropical cyclones that affect the coastal region of Guangxi mostly occur in the western part of North Pacific, and their fast development areas are the ocean surface east to Philippines and the South China Sea. Their sources vary with seasons, and their development is mainly in the northern part of South China Sea in the very summer time, and in the ocean surface east to Philippines in autumn and spring generally, as well as in the middle or southern part of South China Sea near Spratly Islands. Each year the tropical cyclones that affect the coastal region of Guangxi mostly come from this area.

(2) The moving pathways that the tropical storms formed near the coastal region of Guangxi pass can be classified into three types, i.e. northwest type, westbound type and northbound type. Among these three types of routes that tropical storms enter into the coastal region of Guangxi, northwest type appears most frequently. After entering into South China Sea, this type of tropical storms at first lands between Wanning County, Hainan Province and Leizhou Peninsula, and then enters into the Beibu Gulf, moves northwestwards in the Beibu Gulf, lands again in the region 20° N and affects the coastal region of Guangxi. The type following northwest type is the westbound type while northbound type appears least.

(3) According to the data from 1965 to 2010, there were more than 90 typhoons landing and affecting the coastal region of Guangxi over these 45 years, of which 15 typhoons came from the ocean surface east to Philippines into South China Sea, and passed through Hainan Province and Leizhou Peninsula, and then directly landed the coastal region of Guangxi. The storm surges led by the typhoons that directly landed in the coastal region of Guangxi resulted in the increase of water by 111.2 cm on average, which was 2.6 times in comparison with the storm surge led by the typhoons that did not land in the coastal region of Guangxi. The typhoons that landed the coastal region of Guangxi had a longer duration, a higher precipitation and often had increased storm surges coinciding with the diurnal spring tide in the Beibu Gulf, resulting in their superimposition with river discharged flood and huge tide disaster.

(4) The reason that leads to storm surge disasters is mainly related to storm surge caused by strong typhoon system, diurnal spring tide and discharged river flood. At the

time that strong typhoons attack the coastal region, there are heavy rainfalls, which increase the water level in the rivers that pour into sea in the coastal region of Guangxi. As the flood goes down along the river to the sea, the storm surge makes water go up along the river, and the two meet together unexpectedly, resulting in the rise of the water level in rivers. The superposition of maximum storm surge with diurnal spring tide makes abnormally high tide, and leads to the storm surge disaster under strong typhoon weather system.

Acknowledgements

This study was supported by National Nature Science (Grant No. 41266002).

References

- [1] Wu X G. Statistical character analysis of tropical cyclones influencing Guangxi in the last 50 years [J]. Journal of Guangxi Meteorology, 1998, 19: 28 - 31.
- [2] Kong N Q. A weather and climatic characteristic analysis of sudden changes of tropical cyclone intensity after its moving into Beibu gulf [J]. Marine Forecasts, 1997, 14(1): 56 - 63.
- [3] Li Y L, Ou Y, Tang B L, et al. Tropical cyclones activity variation characteristic of Guangxi in recent 50 years [J]. Journal of Meteorological Research and Application, 2009, 30(2): 1 - 3.
- [4] Li Y, Chen L S, Zhang S J. Statistical characteristics of tropical cyclones making landfalls on China [J]. Journal of Tropical Meteorology, 2004, 20(1): 14 - 23.
- [5] Liang J, Li X J, Xie D S, et al. A study on the climate characteristics and the intensity prediction of the tropical cyclones affected in the South China Sea [J]. Marine Sciences, 2008, 32 (12) :29 - 34.
- [6] Zhang X Y, Wen R F. Analysis of tropical cyclones affecting the South China coast [J]. Marine Science Bulletin, 2000, 19(3): 24 - 29.
- [7] Chen B, Qiu S F. Impacts of typhoon course and landform on water level fluctuation in the coastal bays in Guangxi [J]. Guangxi Sciences, 2000, 7(4) 282 - 285.
- [8] Lin J H. Tropical cyclones landing south China coast [J]. Marine Science Bulletin, 1994, 13(6): 92 - 94.
- [9] Feng S Z. Introduction to Storm Surge [M]. Beijing: Science Press, 1982.
- [10] Nong Z L, Li W Q, Wang D, et al. Ocean and Sea Disaster Division in Guangxi Zhuang Autonomous Region. Guangxi Surveillance and Forecasting Center, 2009.
- [11] State Oceanic Administration. Bulletin of Disasters in Chinese Sea and Ocean (1989-2012).
- [12] Guangxi Zhuang Autonomous Region Oceanic Administration Bureau. Guangxi Zhuang Autonomous Region Oceanic Environmental Quality Bulletin (2007-2012).
- [13] Zeng L F. Preliminary study on risk of typhoons on Guangxi coast [J]. Journal of Catastrophology,

1996, 11(1): 43 - 47.

- [14] Chen X Y, Liu H, Dong D X, et al. Analysis of Guangxi major marine disaster risk [J]. Guangxi Sciences, 2013, 20(3): 248 - 253.
- [15] Zhou Y X, Su Y. Analysis on the mechanism of strong typhoon No. 0814 Hagupit's influence on Guangxi [J]. Journal of Meteorological Research and Application, 2009, 30(9): 40 - 41.
- [16] Liang Y. Analysis on storm surge, rain, flooding induced by strong typhoon No. 0814 Hagupit [J]. Guangdong Water Resources and Hydropower, 2009, (5): 31 - 33.

历年影响广西沿海的热带气旋及其灾害成因分析

陈 波, 董德信, 陈宪云, 刘 晖, 邱绍芳

(广西近海海洋环境科学重点实验室 广西科学院, 广西 南宁, 530007)

摘 要: 登陆或经过广西沿海的热带气旋是一种严重的自然灾害, 每年热带气旋所伴随的大风、大雨、风暴潮等灾害造成沿海地区严重的财产损失或人员伤亡。通过对 1950~2012 年影响广西沿海的热带气旋的统计分析发现, 影响广西沿海的热带气旋数量年际变化明显, 最多的年份达 9 个, 最少的年份为 0 个; 热带气旋季节分布具有明显规律性, 每年的 7、8、9 三个月为影响高峰月, 其次为 6、10 月; 热带气旋从菲律宾以东洋面进入南海后穿过海南省和雷州半岛再次登陆广西沿海的次数最多, 该类热带气旋引起的风暴增水平均值为 111.2 cm, 到达非登陆台风增水的 2.6 倍。风暴潮灾害的形成与强台风天气系统、全日大潮、河流下泄洪水直接有关。强台风产生巨浪及降雨, 使入海河口水位上升, 与风暴潮叠加后产生明显的增水, 造成巨大的潮灾。

关键词: 广西沿海; 热带气旋; 灾害成因; 影响分析

Statistical and causes analysis of storm surges along Tianjin coast during the past 20 years

LI Xi-bin^{1,2}, SUN Xiao-yan^{3*}, LIU Yang^{1,2}, ZHANG Qiu-feng^{1,2}, NIU Fu-xin^{1,2}

1. *Tianjin Marine Environmental Monitoring Central Station, State Oceanic Association (SOA), Tianjin 300451, China;*

2. *Tianjin Marine Environmental Monitoring and Forecasting Center, Tianjin 300451, China;*

3. *National Marine Data and Information Service, Tianjin 300171, China;*

Abstract: Based on tidal data statistical analysis for 20 years of Tanggu Marine Environmental Monitoring Station from 1991 to 2010, we concluded that an average of nearly 10 days of 100 cm above water increase took place at Tianjin coast every year. The maximum high tide and average tide of Tianjin coast occurred in summer and autumn, and the maximum water increase also occurred in summer and autumn. Days with water increase more than 100 cm mostly occurred in spring, autumn and winter. Then we summarized the causes of coastal storm surge disaster in Tianjin based on astronomical tide factors, meteorological factors, sea level rise, land subsidence, and geographic factors, et al. Finally, we proposed storm surge disaster prevention measures.

Keywords: Tianjin; storm surge; water increase; statistical analysis; cause analysis

1 Introduction

Storm surge disaster which ranks first in China's marine disasters, occurred from south to north area, almost throughout China's coastal areas. Coast of Tianjin Binhai Area located at the bay bottom of the Bohai Bay with the shallow water and large area of tidal-flat, which is the storm surge disaster-prone seriously area. In recent years, as economic output increases, economic losses caused by marine disasters such as storm surges are increasingly heavier.

The tidal observation well was established at Liumi pier at Tianjin Port on March 15, 1949, and tide was formally observed since January 1, 1950. The tidal observation well was moved to the junction of Tianjin Xingang 20 section and 21 section, and the work boat wharf at East Pier. Until now there have been the tidal observation data for more than 60

years^[1].

In this paper, coastal storm surge disasters during the past 20 years were analyzed and discussed to provide a reference for better coastal storm surge disaster prevention.

2 Summary of severe storm surge disaster at Tianjin coast in recent years

Based on tidal monitoring data for 20 years (1991 to 2010) from Tanggu Marine Environmental Monitoring Station of State Oceanic Administration, much more severe coastal storm surge disasters occurring along Tianjin coast in recent years were analyzed. With the combination of storm surge disaster loss statistics, the more serious process was analyzed and summarized as follows:

(1) On September 1, 1992, the No.16 strong tropical storm made Tianjin coast suffer the most serious strong tide attacks since the founding of our country, and some seawalls were washed away by the sea tide, and a large number of water conservancy projects were destroyed. Tanggu, Dagang and Hangu, these coastal districts and large enterprises, suffered serious losses, which caused direct economic losses up amounted to 400 million yuan;

(2) On August 20, 1997, influenced by "9711" typhoon, storm surge disaster occurred along Tianjin coast, which caused the loss of nearly 200 million yuan;

(3) On October 11, 2003, extratropical storm surge disaster occurred along Tianjin coastal sea area, and tidal disaster spread three coastal areas, which caused direct economic losses of about 120 million yuan.

(4) On August 8, 2005, influenced by Typhoon No. 9 "Matsa" Northward, storm surge disaster occurred along Tianjin coast, and maximum sea level was 30 centimeters above the warning sea level.

Thus, storm surge disasters have a huge impact on the social and economic fields of Tianjin coast area. The comprehensive and detailed analysis on the storm surge disaster of Tianjin coast and its causes has important implications for the work of Tianjin coast area disaster prevention and mitigation.

3 Characteristics statistics of Tianjin coastal storm surge

Tianjin coastal storm surge conditions were analyzed based on tidal data, and we

found that storm surge over the warning tidal level (490 cm) happened 16 times along Tianjin coastal area during 1991 - 2010. The storm surge with the tidal level ultra 500 cm happened 12 times, and the maximum sea level appeared at 17:37 on September 1st, 1992, and the maximum tidal value was 593 cm, which is mainly caused by the interaction of astronomy flood tide and No. 16 strong tropical storm.

Since 21st Century, the highest tide level appeared from October 10 to October 11, 2003, which was influenced by the 9 - 11 levels of strong gales and astronomical tide. Storm surge over the warning water level happened twice along the Tianjin coast, at 04:00 and 17:00, October 11 respectively, and the highest tide level was 533 cm. Statistics of annual maximum tide level during the past 20 years is shown in Fig. 1.

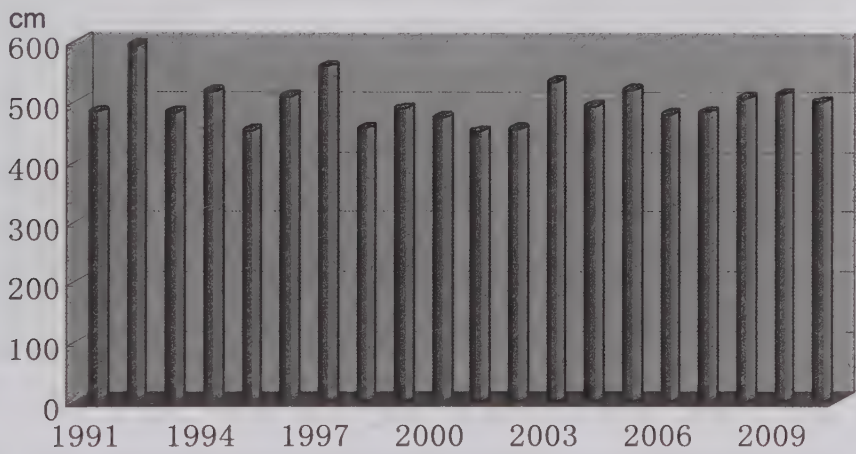


Fig. 1 Statistics of annual maximum tidal level at Tianjin coast from 1991 to 2009

The Tianjin coastal tidal surge was analyzed by month. From the statistics of monthly tidal characteristics in Tab. 1 below, we can see that, during recent 20 years, the highest tide level value along Tianjin coast occurred in September, and the value amounted to 593 cm. The highest average high tidal level was 427 cm, which also occurred in September. The highest mean tidal level value occurred in August, and the value amounted to 291 cm, and the average tide level in 6 - 9 months was much higher.

Water increase conditions of Tianjin offshore during 1991 - 2009 were conducted statistics based on the combination of tidal data and the astronomical tide harmonic data [2, 3, 4]. Along Tianjin coast, days with water increase ultra 50 cm amounted to 1 535, with an average of 76.8 days per year, of which days with water increase ultra 100 cm amounted to 186, with an average of 9.3 days per year. For the sector in 2003, days with ultra 100 cm and 50 cm were 7.9 and 71 respectively before 2003 and after 2003, and the values were 11.4 and 80 respectively. The specific statistics are shown in Fig. 2:

Tab. 1 Statistics of monthly tidal level characteristics of Tianjin coast (unit:cm)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Mean tidal level	234	237	251	261	270	281	289	291	281	265	248	234
Mean high tide	368	372	388	389	396	405	409	426	427	411	414	393
Highest tide level value	474	513	500	504	505	493	540	559	593	533	505	464

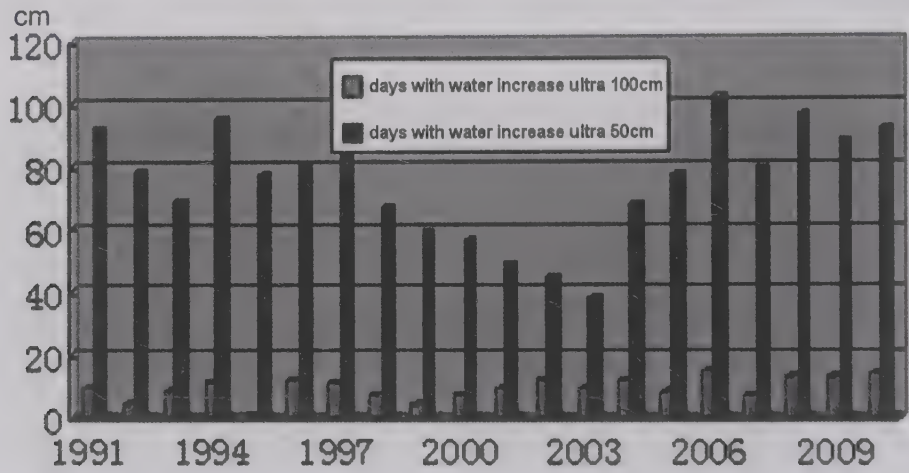


Fig. 2 Statistics of water increasing days with the water increase ultra 50 cm and 100 cm along Tianjin coast

Statistics of the maximum water increase along Tianjin coast during the period of 1991 - 2010 are shown in Fig. 3 and Tab. 2. During the period of 1991 - 2010, the largest water increase value of each year was ultra 100 cm. Among them, the maximum storm surge value occurred in November, 1997, with water increase value up to 227 cm. From the monthly view, the annual maximum water increase appeared in 2 - 12 months, and the largest water increase value appeared in 8 - 11 month, mainly in summer and autumn.

The monthly analysis results of storm surge water increase are shown in Fig. 4 and 5. The storm surge water increase ultra 100 cm happened in each month during the period 1991 - 2010. Concerning the occurrence time, it showed obvious seasonal characteristics, among which, from June to September, the number of water increase occurrence days was the least, and from October to December and January to April, the number of water increase occurrence days was the most. The most water increase happened in spring, autumn and winter.

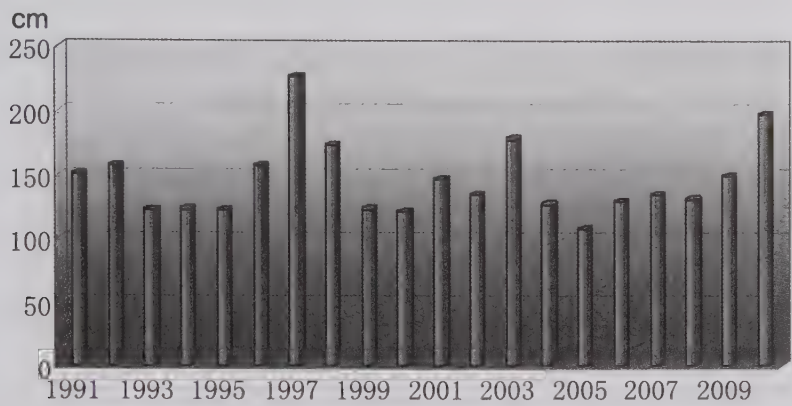


Fig. 3 Annual statistics of maximum water increase along Tianjin coast during the period 1991 - 2010

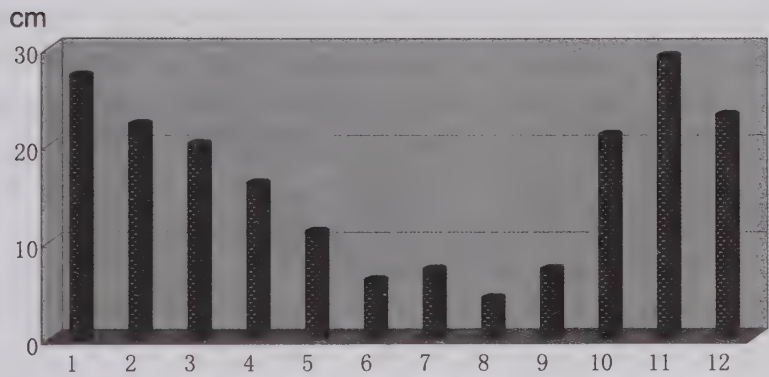


Fig. 4 Monthly distribution with water increase ultra 100 cm along Tianjin coast during the period 1991 - 2010

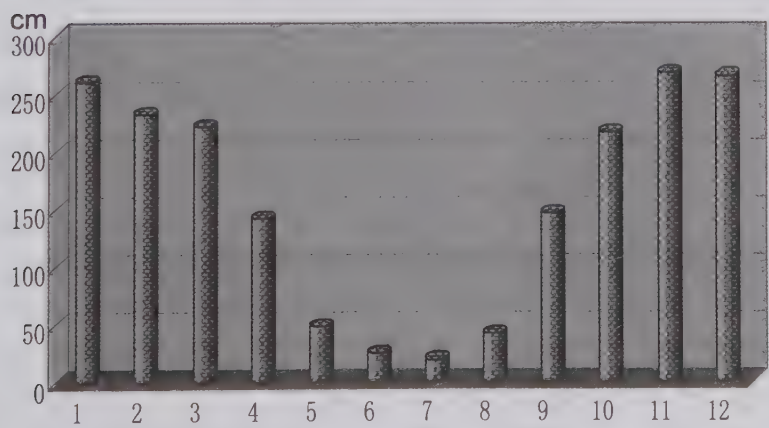


Fig. 5 Monthly distribution with water increase ultra 50cm along Tianjin coast during the period 1991-2010

Tab. 2 Monthly statistics of maximum water increase happened along Tianjin coast during the period 1991 - 2010

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
The month when water increase happened	3	9	11	8	2	10	11	11	3	10
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
The month when water increase happened	10	2	10	11	3	10	10	12	4	12

4 Cause analysis of storm surge disaster

Storm surge disaster along Tianjin coast is often influenced by various factors jointly, mainly including, the astronomical tide factors, meteorological factors, sea-level rise,land subsidence and geographic factors, et al. ^[5, 6, 7] These various factors are superimposed, exacerbating storm surge disasters exacerbated.

4.1 Astronomical tide factors

Concerning Tianjin coast, astronomical tide is the most important factor in the formation of storm surge. Taking astronomical tide in 2010 as an example, the astronomical tide characteristics were calculated. (see Tab. 3)

Tab. 3 Statistics of astronomical tide along Tianjin coast month by month in 2010 (unit: cm)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Mean sea level	234	243	252	258	270	283	292	289	283	274	257	239
The average high tide	339	349	360	367	380	392	402	402	395	384	367	346
The average high tide value	375	379	386	404	414	438	444	437	429	425	409	385

Among these characteristics, the average high tide of Tianjin coastal astronomical tide was minimum with value 339 cm in January, and the average high tide of astronomical tide was maximum with value up to 402 cm in the flood season from July to September, which was 63 cm higher than that in January, and the highest astronomical tide values occurred in July, with value up to 444 cm which was only 46 cm less than the current warning tidal level (490 cm) of Tianjin coast. Tropical cyclone activity is frequent during the flood season when astronomical high tide occurs, and coinciding with the effect of meteorological system, storm surges with high tide can easily happen, and produce larger

water increase^[8]. Combined with Tab. 1, storm surge (593 cm) caused by No “9216” strong tropical storm in 1992 and storm surge (559 cm) caused by No “9711” typhoon in 1997, were the highest and the second high tidal level respectively since the Tanggu Marine Environment Monitoring Station has recorded the storm surge, which all occurred in August and September, and these were all caused by strong meteorological system and astronomical tide superposition. Therefore, storm surge disaster prevention and mitigation work should be focused on during the flood season.

4.2 Meteorological factors

There are three main kinds of meteorological factors that caused Tianjin coastal storm, namely, tropical cyclone, cold air and extratropical cyclone. Thus, Tianjin coastal storm surges are thus divided into extratropical storm surges and typhoon storm surge^[9]. Extratropical storm surge generally caused by cold air and extratropical cyclone, can occur throughout the year, but it occurs mostly in spring and autumn. Typhoon storm surge mostly occurs in summer and autumn, and the number of storm surge caused by typhoons or tropical cyclones along Tianjin coast is fewer, but the typhoon storm surge is fierce and water increase is very large, which causes great harm. According to statistics, during the period 1991 – 2000, typhoon storm surge along Tianjin coast occurred four times, in 1992, 1997, 2000 and 2005 respectively, which all caused significant economic losses^[10].

From the above Fig. 4 and Fig. 5, we can see that storm surge water increase ultra 100 cm occurred in each month during the period 1991-2010. Concerning the time of its occurrence, it displayed obviously seasonal characteristics. Number of days that water increase occurred was maximum from October to December and January to April, that is, increasing water mainly concentrated in spring, autumn and winter. This is mainly because at this cold and warm alternating time, it easily leads to storm surges of cold air and extratropical cyclone systems active, resulting in the increased water.

4.3 Sea-level rise

Sea-level rise is divided into two parts, one for absolute sea level rise, and the other part is the relative sea level rise.

Absolute sea level rise is due to the factors, such as the expansion of sea water, the polar ice caps and continental glacier and ice cap melting caused by global the warming.

Relative sea-level rise is caused by regional tectonic subsidence, sediment compaction and anthropogenic subsidence factors.

Trend of sea level change is calculated and fitted by using the least squares method

based on tidal data, and the average sea level of Tianjin offshore is slowly rising^[11, 12], with the rising rate of about 3.4 mm/a (see Fig. 6).

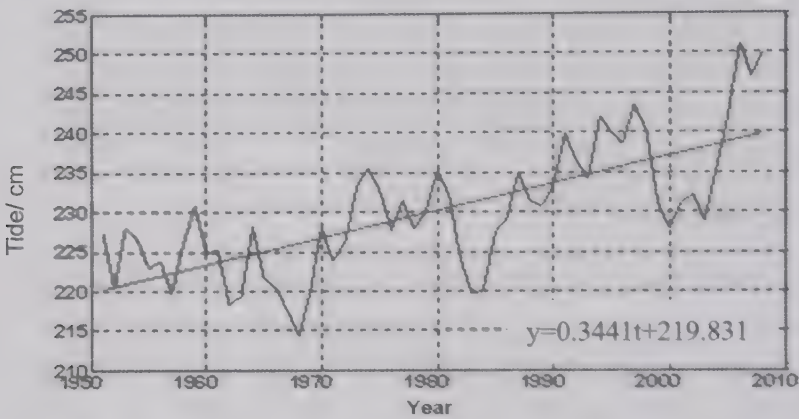


Fig. 6 Sea level change trend of Tanggu Marine Environmental Monitoring Station

When sea level rises, foundation level of storm surge is lifted, thereby significantly shortening the return period of the extreme high tides, increasing the chance of seawater overflowing seawall, thus exacerbating the destructive force of storm surge disasters

4.4 Ground subsidence

Due to the long-term of exploitation of groundwater in coastal area of Tianjin city, and floor load increased by large coastal engineering buildings, the ground subsidence speeds up. According to Tianjin city ground subsidence monitoring data, it shows that part of the ground elevation in Binhai New Area is under the sea level. Land subsidence of year results in that partial section of embankment has been under fortification standards, reducing moisture resistance ability, which increases the storm surge frequency and the extent of the disaster.

Tab. 4 Annual sedimentation value change table of Tianjin coastal district

Year Time	1993	1994	1995	1996	1997	1998	1999	2000	2006	2007	2008	2009	2010
Tanggu	18	22	7	13	8	18	12	18	23	35	24	20	26
Hangu	41	38	23	27	18	29	33	33	23	29	18	14	24
Dagang	22	29	6	20	19	21	13	19	20	26	26	21	25

4.5 Geographical factors

Tianjin locates in gulf bottom of the Bohai Bay. When its tidal signal is mainly

transported from the open sea, it is difficult to spread around, and it will lead to a sharp rise in the water level inside the bay, forming long time high tide, and it is highly conducive to the formation of storm surge disaster.

5 Conclusions and suggestion

Based on statistical analysis of 20 years' tidal data from Tanggu Marine Environment Monitoring Station during the period from 1991 to 2010, we found that:

(a) During the past 20 years, the highest tidal level and the highest mean high tide of Tianjin coastal area all occurred in September, and the largest water increase all appeared between February to December during the period 1991 - 2000. Annual average number of days with water increase ultra 50 cm was about 76.8, among which annual average number of days with water increase ultra 100 cm was about 9.3, and it showed obviously seasonal characteristics. Water increase process mainly occurred in spring, autumn and winter.

(b) This paper analyzed the main factors resulting in Tianjin coastal storm surge, including astronomical tide factors, meteorological factors, sea-level rise, land subsidence, and geographical factors, and the above factors were analyzed based on the measured data.

(c) In this paper, by statistical analysis of tidal data from Tanggu Marine Environment Monitoring Station, it is designed to provide the basis for the construction of marine defense projects, providing technical guarantee for the government disaster prevention and mitigation. This paper proposed that quality of coast dam and sea block facility should be improved, and moisture resistance ability should be strengthened^[13], preventing the storm surge system and marine disaster early warning work needed to be strengthened. Strengthening the propaganda work of storm surge related knowledge to the public is needed, to strengthen people's consciousness of storm tide and enhance the port managers' prevention awareness, and all together to resist the storm surge disaster.

References

- [1] Li X B, Zhang Q F, Yao Z G. Characteristic analysis of Tianjin offshore tide [J]. Marine Forecasts, 2011, 28 (2): 41 - 47.
- [2] Huang Z K, Huang L. Tidal theory and calculation [M]. Qingdao: China Ocean University Press, 2005: 12 - 88.
- [3] Wang C H. A model of the harmonic analysis of tides [J]. Marine Forecasts, 1995, 12(4): 71 - 76.

- [4] Wu S H, Wang X N, Song S, et al. The general status and statistics of storm surges in the coast area of Tianjin [J]. Marine Forecasts, 2002, 19(1): 29 - 35.
- [5] Zhang X Y, Shao R M, Gao M C. Research on the cause of formation of the coastal sea storm in Tianjin and its prevention and reduction measure [J]. Journal of Tianjin Institute of Technology, 2005, 21(2):60 - 63.
- [6] Shi P, Guo H T. Tanggu extratropical storm surge and its research [J]. Marine Forecast Service, 1984, (01): 33 - 42.
- [7] Liu P S, Wang X N. Preliminary study of the Bohai storm tide [J]. Studia Marina Sinica, 1984(03):1 - 17.
- [8] Xu F X. Analysis of causes of three severe storm surge disasters in Tianjin and strategy of disaster prevention [J]. Marine Forecasts, 2002, 19(1):36 - 42.
- [9] Hou S M, Sun Z X, Sheng C Y. Weather analysis of Bohai sea storm surge caused by extratropical cyclone [J]. Scientia Meteorologica Sinica, 2009,29(2):220 - 224.
- [10] Wa Z X. Study on Marine Disasters and Their Impacts in Tianjin [J]. Marine Science Bulletin, 2006, 25(2): 41 - 45.
- [11] Zuo J C, Chen Z Y, Zhou T H. Eigen anlysis and prediction of relative sea level changes along the China coast [J]. Oceanologia Et Limnologia Sinica,1995, 26(3):331 - 337.
- [12] Fan W J, Zhang A J. Study on water level variations and interrelations of its extremes and surface wind at tanggu station [J]. Marine Science Bulletin, 2006, 25(4):29 - 35.
- [13] Duan Z H. Analysis and Countermeasures of Bohai coastal storm surge characteristics of Tianjin city [J]. Marine Forecasts, 1995, 12(1): 37 - 41.

天津沿海风暴潮灾害近20年统计及其成因分析

李希彬^{1,2}, 孙晓燕³, 刘洋^{1,2}, 张秋丰^{1,2}, 牛福新^{1,2}

(1. 国家海洋局天津海洋环境监测中心站, 天津 300451; 2. 天津市海洋环境监测预报中心, 天津 300451;

3. 国家海洋信息中心, 天津 300171)

摘 要: 根据塘沽海洋环境监测站从 1991~2010 年, 20 年的潮汐资料进行统计分析, 分析得到天津平均每年发生近 10 年的 100 cm 以上的增水过程, 天津沿海夏秋两季的最高潮位和平均潮位最高, 且最大增水值多出现在夏秋两季, 超过 100 cm 的增水天数多集中在春季和秋冬季, 并从天文潮因素、气象因素、海平面上升、地面沉降, 以及地理因素等, 总结了天津沿海风暴潮灾害的成因, 最后提出了相应的风暴潮灾害防范措施。

关键词: 天津; 风暴潮; 增水; 统计分析; 成因分析

Island instantaneous coastline extraction based on the characteristics of regional statistics of multispectral remote sensing image

WANG Feng^{1, 2}, LIU Shu-ming², LU Wen-hu², DU Qiong-wei², JIANG Wei-nan², LIU Jin²

1. College of Oceanography and Environmental Science of Xiamen University, Xiamen 361005, Fujian province, China;

2. Notional Marine Data and Information Service, Tianjing 300171, China

Abstract: This study adopted IKONOS remote sensing images and selected spectral characteristic areas, through regional pixel statistics and calculating weight coefficients of each band, processed the images with the spectral normalized method, which made the features of islands, land and water features more obviously in the images. On this basis, the OTUS was used to determine the optimal segmentation threshold, and the normalization image binarization was made, thus the island coastline was extracted. This method used the characteristic curve method to separate the land and water, obtained the binarization images and maintained the original edge effectively. The coastline that was extracted by Binary Morphology was continuous, reliable and high signal-to-noise ratio. The results showed that this method could extract the coastline fast, simply and effectively, which had the practical value.

Keywords: coastline extraction; islands; spectral characteristics of regional statistics; Binary Morphology; IKONOS

Introduction

China is rich of islands, therefore protection and management of the island has become increasingly important. Island coastline, a basic feature of the island, is the boundary between island and seawater, and coastline data play an important role in the management of island security. In the implementation of island monitoring and surveillance, the most direct method is making use of remote sensing image to extract the island instantaneous coastline, which can be extracted whether by the artificial judgment or

Received on Mar. 24, 2014

*Corresponding author: wangfengbest@hotmail.com

by the computer automatic processing. Artificial judgment is time-consuming, laborious and be likely influenced by subjective factors, while the computer automatic processing is relatively fast and objective, so, finding an effective method of automatic extraction of island coastline is important for promoting work efficiency and data accuracy.

At present, automatic extraction method is more suitable for mainland coastline, and mature algorithms mainly take the threshold segmentation method based on gray histogram statistics ^[1], segmentation method based on region growing ^[2], and segmentation method based on gray level co-occurrence matrix feature description method ^[3], and most of these methods are for the single band remote sensing image (grayscale image). The multispectral remote sensing image coastline extraction method has drawn more attentions from various scholars, and the application of spectrum characteristic curve comparison and multiband superposition of edge information method appear constantly ^[4-6]. This paper puts forward the island instantaneous coastline extraction method of multispectral remote sensing image, based on the typical image of sea and land statistics, which is realized by the normalization of multiband image superposition.

1 Experimental data and research area

The research area is located at the Qianhai bay in Shenzhen of Guangdong province in China: Dachan Island, Mazhou Island and the nearby sea area, as shown in Fig. 1. The topography of Dachan island is low mountain and hills with lush vegetation and part of the island land has been developed by human. There is about 1 km from the south of Mazhou Island to Dachan Island. Dachan Island is supposed to have 2 independent small islands, which has been developed completely and combined as one island. Remote sensing image of the research area as shown in Fig. 2, which is the wavelength synthetic images of the IKONOS red, green and blue, was taken at 03:11 on Jul. 27, 2008 in GMT.

This paper takes IKONOS satellite remote sensing image as the data source to research. IKONOS satellite was launched on Sep. 24, 1999, and it is the first in the world to provide high resolution satellite images of commercial satellite remote sensing with the acquisition 1 m resolution panchromatic and 4 m resolution multispectral imaging, IKONOS satellite images band information as shown in Tab. 1.



Fig. 1 Research area(which is surrounded by the square)

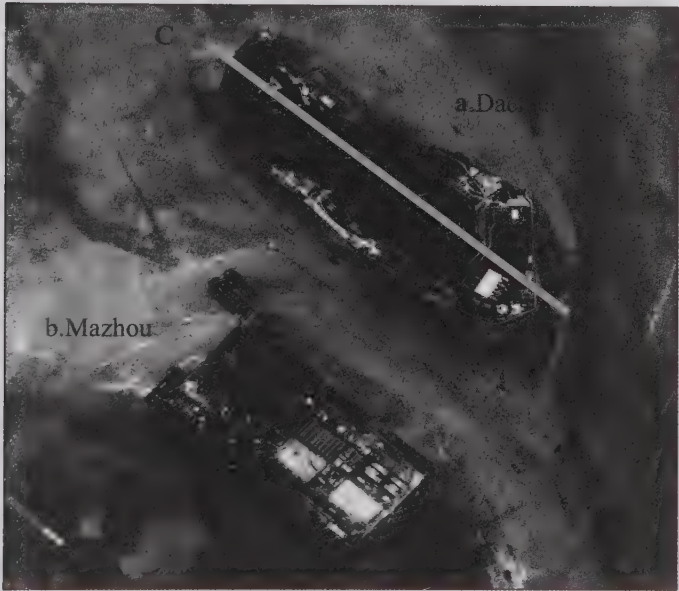


Fig. 2 IKONOS Image(a. Dachan Island and b. Mazhou Island)

2 Remote sensing data preprocessing

The aim of preprocessing is to restrain or eliminate the distortion and degradation in the image, and to enhance some characteristics of image. The preprocessing results affect the subsequent remote sensing image processing and analysis directly. The preprocessing steps include: atmospheric correction, image enhancement and geometric precision correction.

Tab. 1 Spectral information of IKONOS image

Band	Spectral value / μm	Resolution / m
Blue	0.45 - 0.53	4
Green	0.52 - 0.61	4
Red	0.64 - 0.72	4
Nir	0.77 - 0.88	4
Pan	0.45 - 0.90	1

2.1 The atmospheric correction

Atmospheric correction is primarily to eliminate the material influence of water vapor in the atmosphere, oxygen, carbon dioxide, methane and ozone on clutter reflections, eliminate the influence of atmospheric molecules and aerosol scattering and obtain real reflectance data of the features [7].

This article uses the dark-object methods for atmospheric correction. The basic principle of this method is to assume that the dark-object area exists in the remote sensing image for the correction, and the island surface has lambertian surface reflection and atmospheric properties. To ignore the atmospheric multiple scattering irradiation effect and adjacent pixels, and under the premise that the diffuse emission effect can be ignored, the brightness values of dark-object relatively increase because the dark-object with low reflectivity or radiation brightness is influenced by the atmosphere, and this part can be thought as the brightness of the increase due to the atmospheric path radiation. Dark-object methods are used to calculate the path radiation and applied in the appropriate atmospheric correction model, to obtain the real emission rate by the calculation after getting the corresponding parameters [8].

Using this method to assume there is small DN value (approximately 0) dark-object in the remote sensing image but the DN value is relatively increased by the influence of atmosphere, thus it could be agreed that the number of DN value is decided by the atmosphere. Therefore, using the other pixel minus DN value of dark-object to reduce the influence of atmosphere on the remote sensing images could realize the atmospheric correction indirectly.

2.2 Image enhancement

Gaussian filter is a kind of linear smoothing filter, which is used for eliminating the Gaussian noise, and widely used in noise reduction during the image processing. Smoothing filter uses the filter mask scanning each pixel in the image, with a mask to

identify the average grey value within the neighborhood pixels instead of each pixel value of the image. Gaussian filter has fast speed of calculation, but it could cause blur while removing the sharp noise, especially in reducing the extraction accuracy of coastline. Gaussian filter is the filter with weight, and the weight in the center is greater than that in the adjacent pixels, so that it could overcome the boundary effect to enhance the accuracy of island instantaneous coastline extraction in this article.

Furthermore, the mask center has the biggest pixel weight so that the farther the position is from the center, the smaller the effects will be. The coastline in the research area is much more smooth, thus this article uses the ENVI image platform to process the IKONOS image of each band by the size of Gauss "7" x 7" low-pass filter to enhance and denoise the processing, which could improve the accuracy of instantaneous coastline extraction and also reduce the blur of image.

2.3 Geometric precision correction

Under the influence of imaging projection method, exterior orientation element changing, the uneven of sensing medium, earth curvature and topography change, and earth rotation et al., remote sensing image has geometric deformation, and the process to eliminate the geometric deformation is called geometric correction.

Geometric precision correction uses (Ground Control Point, GCP) to correct any geometric distortion which is caused by various factors. The principle is to use GCP data to simulate the geometric distortion process of original satellite images, establishing a distortion of the original image spatial domain geographic space corresponding relationship between the national standards, using the corresponding relationship to transform all the elements of the distortion of space to the corrected image space ^[9]. Therefore, the accuracy of GCP affects the precision of geometric correction directly.

Due to environmental restrictions, it is difficult to obtain more GCP in water and island area, and the result is not satisfactory by using general method for correction. The IKONOS remote sensing image has RPC files and DEM data. This paper adopts Rational Function Model (RFM) with selecting a few control points to realize the essence of remote sensing image geometric correction.

3 Instantaneous coastline extraction method

3.1 Analysis of IKONOS multispectral band characteristics

Each brightness value of the pixels in the remote sensing image represents the

average radiation value of the ground object, and it changes with the composition, texture, conditions, surface characteristics, and the use of electromagnetic wave varies.

Sunlight absorption, reflection and transmission of water are changing with the wavelength. Generally, absorption is greater than the reflection and transmission ^[10, 11]. The reflection of water is very low in the visible area normally, and the maximum transmission wavelength of light is about between 450 nm - 550 nm in the clear water, and peak wavelength is about 480 nm. The water spectral attenuation characteristics is shown in Fig. 3. In blue and green wavelengths, seawater has the feature of the weakest scattering least attenuation coefficient, and strongest penetration. Therefore, in the shallow area, blue and green wavelengths can be transmitted through water, reflect the bottom. The reflectivity of water further is reduced with the increase of wavelength, and water is almost fully absorbed to near infrared band. So, on the satellite images of near infrared wave band, the color of water is dark generally.

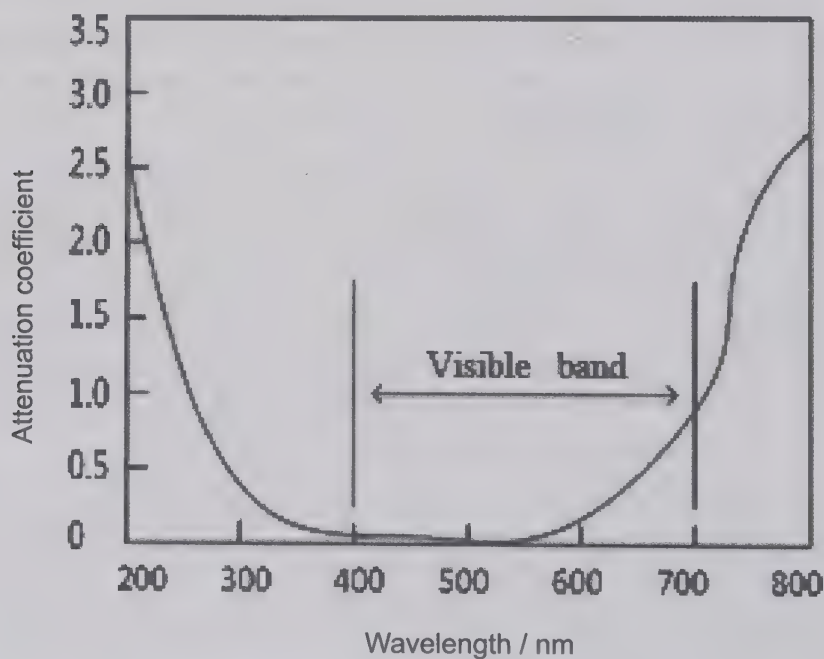


Fig. 3 Attenuation curve of the water spectral characteristics

To compare and analyze the radiation luminance values of IKONOS in four band ^[6], it is found that near the land and sea borders, the changing ranges of radiation brightness values are different, and the changes of near infrared band and red band changes are great, as Fig. 4 shows. To calculate the change rate of radiation brightness values of four band that near the land and sea borders, the results are related with radiation values from

seawater to island, and with the island and water rate respectively. The greater rate of change indicates the radiation change from seawater to island is bigger, and island and sea borders are more obvious.

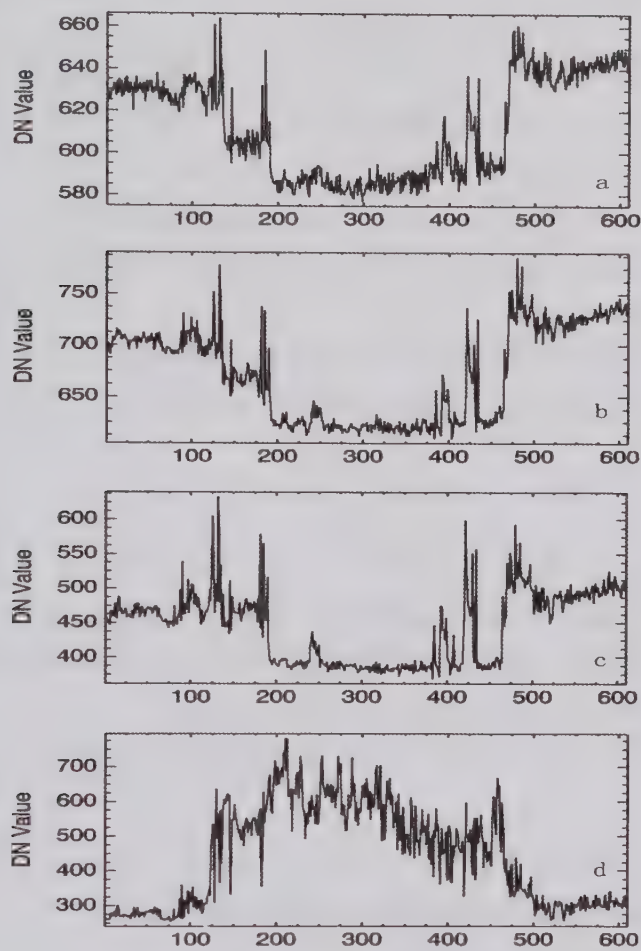


Fig. 4 Spectral band radiance profiles of the IKONOS image

(a-d denote the blue band, green band, red band and near infrared band of C-D respectively)

3.2 The image spectral normalization

According to the analysis results of the section 4.1, the greater radiation brightness value means more successful of the separation of land and water in the band. Method for the weight calculation of IKONOS in 4 bands: selecting 2 reference areas (A and B) on both sides of the island and sea in band i , A is located in the island area, and B is on the sea area. Supposing that the average radiation intensity values are $L_A(i)$ and $L_B(i)$, the

change of radiation intensity values is as follows:

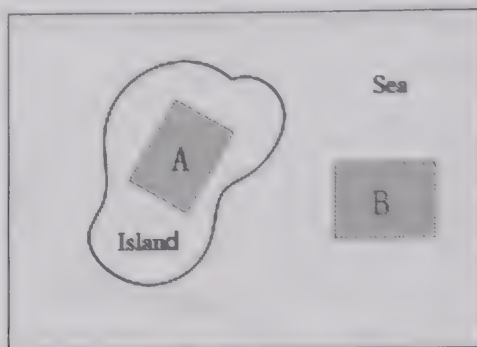


Fig. 5 Schematic diagram of the selected reference area

$$VL(i) = L_A(i) - L_B(i) \quad i \in [1, 4] \quad (1)$$

Corresponded weight of i band:

$$W_i = \frac{VL(i)}{\sum_{n=1}^4 VL(n)} \quad i \in [1, 4] \quad (2)$$

To make full use the information in each band, the images in different bands are processed normalizedly, which could enhance the diversity of spectrum characteristics and popularize the algorithm. The normalized spectrum E is calculated by the following formula (0.3), M and N represent data tag horizontal and vertical size of the matrix.

$$E(x, y) = \sum_{i=1}^4 L_i(x, y) \times W_i \quad x \in [1, M] \quad y \in [1, N] \quad (3)$$

3.3 The normalized spectrum image binarization

The image contains the target, background and noise, and we could set a threshold as T for extracting the target from the multiple-valued image directly, and divide the image into two parts: one group of pixels (target) greater than the threshold T and the other group of pixels (background and noise) less than the threshold T .

Otsu algorithm was proposed by Otsu in 1979, and this method was derived by the analysis and judgment which is an automatic threshold segmentation method without parameters unsupervised. Its principle is to use the image histogram to separate the image into 2 parts, target and background, and use the maximal variance to determine the optimal segmentation threshold for obtaining the corresponding binary image. Otsu algorithm is very simply, clear and fast, and it is also sensitive to the noise and target size. In this article,

we also use the Otsu Method to process the remote sensing images.

3.4 Using the binary morphology method to detect the coastline

The original idea of Binary Morphology is to extract corresponding shapes to analyze and recognize the image [4]. Binary Morphology is composed by a set of morphological operations, and there are four basic operations: dilation, erosion, opening and closing, and its operation object is the collection. To determine the structure of the image, we must consider the relationship between the various parts of the image, and develop the collection of images and elements for the image processing, meanwhile we have to notice the size of structure elements and images.

After the binarization, we get the binary image of land and water. The coastline essence images (A) are extracted from the binary images, and $\beta(a)$ is the edge detection. Usually, the erosion operation between b and a is used, then we get $\beta(a)$ by the difference set of erosion result and a:

$$\beta(A) = A - (A \ominus B)$$

(4)

Extracted edge could maintain the correct position of images, but also need further refining 2 pixels of the edge. After obtaining the image edges, we check the connectivity of edges and exclude the outlier noise, then refine the edges and ultimately get the coastline [5].

4 Research area coastline extraction

First, the ENVI software is used to preprocess IKONOS remote sensing images by the method that is mentioned in Part 2. And then, a typical area in the image is selected, such as rectangular region in the Dachan Island and Mazhou Island (L1 and L2 as shown in the Fig. 6). The area L1 is totally covered by the vegetation which is the typical natural land in the island. L2 as a typical area of artificial facilities, has land features with high brightness and low brightness area also. There are 3 selected sea areas in the image, S1, S2 and S3, S1 in the high brightness of sea area, S2 in the low brightness and S3 in the medium brightness of sea area

After selecting a typical areas on land and sea, we start to complete the statistics and calculation of sea multi-band pixel value and weighting factor, and the result is shown in Tab. 2. It shows that island area and sea have the smallest difference of mean pixel in the blue band with the minimum weight coefficient of 0.050, and there is little difference on the brightness in each pixel elements in the typical area. On the contrary, in the near-infrared

band, there is the maximum weight coefficient 0.682 between island area and seawater. Tab. 2 also shows a trend that with the increasing wavelength, land area and seawater pixel gap become increasingly apparent.

After obtaining the weight coefficient for each band in typical areas, we preprocess spectral image for the normalization. The results are shown in Fig. 7. The processed image is more distinct and has less affection from the noise. The spectrum normalized contrast images of island area and seawater are more obvious, which partly reduces the impact of noise points.

The Otsu variance method is used to calculate the gray histogram first, and then we figure out the interclass variance of each grey level, and determine the optimal threshold finally. The results of normalized spectral image binarization are shown in Fig. 8. The island profile is presented clearly, and we can also find the outline of the ship on the sea. Finally, the binary morphology and visual interpretation are used to extract island instantaneous edges and delete isolated noise from ships, and we can see the final coastline in Fig. 9.

Tab. 2 The weight coefficient statistics for each band of IKONOS image

Band	Island area		Sea area		Weight Coefficient
	Mean	Stdev	Mean	Stdev	
blu	630.348731	27.874797	617.6549	9.593752	0.049676524
grn	708.245658	53.441319	682.6947	19.62781	0.099992185
red	484.165526	68.959783	441.2513	29.00228	0.167942509
nir	439.29722	129.9064	264.9268	40.11173	0.682388781



Fig. 6 Typically selected areas

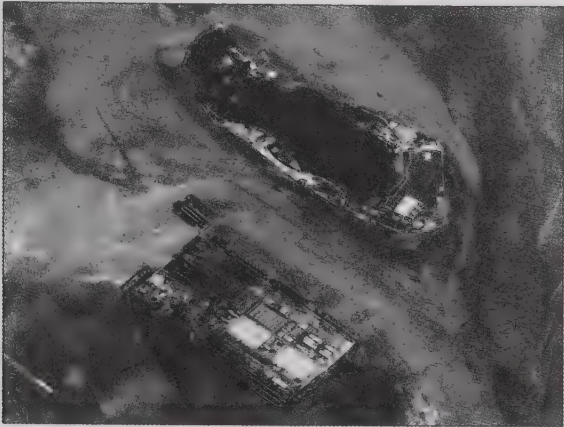


Fig. 7 Normalized image



Fig. 8 Binarized image

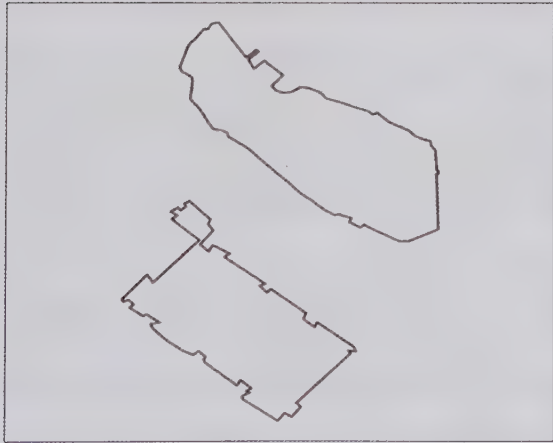


Fig. 9 Result of the island coastline

5 Conclusion

The results show that separating the land and water by the method of characteristic curve could maintain the effective edges of original images, and extracted coastline is more reliable and has high signal to noise ratio by using the binary morphology. Experimental results show that the algorithm proposed in this article is very simple and fast, and it could extract the coastline effectively in the case of much spectral information and enhance the efficiency. In the remote sensing image, near-infrared (0.76 - 3.0 μm) is the main band of water analysis. Thus in the experiment, we can obtain the best accurate results after having near-infrared information.

The coastline mentioned in the article is not the same in the chart, but it is referred to instantaneous and distinctive coastline boundary in the remote sensing image^[14-16]. The coastline extraction model uses the unique advantages of spectral information and morphological characteristics of the image for extracting the edge information of multispectral and hyperspectral remote sensing image effectively. Furthermore, the algorithms mentioned in the article is very simple and efficient, and it could also be adopted in the engineering calculations for the practical value.

References

- [1] WU Hao, LIU Zhengkai, ZHANG Rong. A Study of Bridge Recognition from Landsat TM Images [J]. *Journal of Remote Sensing*, 2003, 7(6): 479 - 480.
- [2] Chen Zhong, Zhao Zhongming. A Multi-scale Remote Sensing Image Segmentation Algorithm Based on Region Growing [J]. *Computer Engineering and Applications*, 2005, 35: 8 - 9.
- [3] GONG Jie, YANG Shi-yuan. The Detection and Classifying Technology Research of the SAR Image [J]. *Journal of Beijing University of Posts and Telecommunications*, 2005, 2(4): 100 - 102.
- [4] YAO Xue-juan. Coastline Extraction of Remote Sensing Images Based on Spectrum Curve Method [J]. *Journal of Guangdong Radio & Television University*, 2009, 78(18).
- [5] Xiong Xianming, Yao Xuejuan, Teng Huizhong. Based on Spectral Signatures of Remote Sensing Images [J]. *Chinese Journal of Scientific Instrument*, 2007, 28(8): 195 - 198.
- [6] YUAN Jianshen. Land and Water Separation Method Based Multispectral Remote Sensing Images of Marine [J]. *Computer & Information Technology*, 2011.
- [7] Qian Lexiang. Digital image processing of remote sensing and geographic feature extraction [M]. Beijing: Science Press, 2005.
- [8] ZHENG Wei, ZENG Zhi-yuan. Dark-Object methods for Atmospheric Correction of Remote Sensing Image [J]. *Remote Sensing For Land & Resources*, 2005.

- [9] CHAO Zhen-hua, CHEN Quan-gong. Measurement of Physiological Indices of Three Alfalfa Varieties under Invitrodrought Stress [J]. Grassland and Turf, 2005.
- [10] Medina-Carnicer R, Madrid-Cuevas F J. Unimodal Thresholding for Edge Detection Pattern Recognition [A]. 2007
- [11] Gianearlo B, Silvana D, Raimondo D. Semiautomatic coastline detection in remote sensing images [A]. Proc. of the IEEE2000 Int'l Geoscience and Remote Sensing Symp, (IGARSS00), Hawaii.
- [12] Otsu N.A.A Threshold Selection Method From Gray-level Histograms [J]. IEEE Transactions on Systems, Man&Cybernetics, 1979, SMC-9(1): 62 - 66.
- [13] Chen Ming-quan, Sun He-li, Li Xi-yu, et al. Coastline Detection and Extraction for Remote Sensing Image by Using Matlab [J]. Journal of Hubei University of Technology, 2011, 26(5).
- [14] ZHANG Yong-ji, YAN Dong-mei, ZENG Luan, et al. A Method Based on The Related Information of Neighborhood for Extracting Coastal Line [J]. Journal of Institute of Command and Technology, 2005, 16(6): 88 - 92.
- [15] Li R, Ruijin D K. Digitaltide-coordinated shoreline [J]. Marine Geodesy, 2001, 25(1/2): 27 - 36.
- [16] Pesaresi M, Benediktsson J A. A New Approach for the Morphological Segmentation of High-resolution Satellite Imagery [J]. IEEE Transactions on Geoscience and Remote Sensing, 2001, 39(2): 309 - 320.

基于特征区域统计的多光谱遥感影像 海岛瞬时岸线提取

王 丰^{1, 2}, 刘书明², 卢文虎², 杜琼玮², 姜伟男², 刘 金²

(1. 厦门大学海洋与环境学院, 福建 厦门 361005; 2. 国家海洋信息中心, 天津 300171)

摘 要: 本研究采用 IKONOS 遥感图像, 选取波谱特征区, 通过区域像元统计并计算各波段权重系数, 将影像进行波谱归一化处理, 使归一化的影像岛陆与海水特征更明显。在此基础上, 采用最大类间方差法确定最佳分割阈值, 对归一化的影像进行二值化, 从而提取海岛岸线。该方法采用特征曲线法进行水陆分离, 得到的二值图像保持了原图的有效边缘, 采用二值形态学提取的海岸线连续可靠、信噪比高。结果表明, 该方法简单、快速, 能有效提取海岸线, 具有实用价值。

关键词: 岸线提取; 海岛; 波谱特征区域统计; 二值形态学; IKONOS

Research on the evaluation of marine function zoning and its practice in China

HUANG Nan-yan^{1,2}, WANG Qian², XU Wen-bin², LIN Ning², LI Ping³

1. *College of Physical and Environmental Oceanography, Ocean University of China, Qingdao 266003, Shandong province, China*

2. *National Marine Data and Information Service, Tianjin 300171, China*

3. *Marine Resources Development Center of Guangdong Province, Guangzhou 510220, Guangdong province, China*

Abstract: The evaluation of marine function zoning (hereinafter referred to as MFZ) is an important part of MFZ. This paper studies the principles of MFZ evaluation and the evaluation procedures. It is proposed that three main aspects, including the evaluation of MFZ implementation situation, the evaluation of the performance effects and the evaluation of the changes of dependent conditions, are the top priorities in establishing an evaluation indicator system framework. The evaluation of MFZ implementation situation includes assessing the general situation of MFZ and the degree of implementation and public participation. The evaluation of the performance effects involves the assessments of the achievements and the existing problems in the rectification and standardization of utilizing the sea areas, protecting marine resources and environment, and promoting marine economic development. The evaluation of the changes of dependent conditions includes the assessments and measurements of the changes in the social and economic conditions, the use demands of marine industries, marine resource conditions and marine environmental conditions. This paper provides the means of integrating quantitative and qualitative approaches into the scientific and systematic evaluation on MFZ. The evaluation results can determine whether MFZ needs to be altered or not. The results also provide an important reference basis for determining whether a slight or great alteration is justified. To illustrate the utility of the MFZ evaluation indicator system, an evaluation example is given. Further studies are needed to make the evaluation of MFZ more scientific, reasonable, fair and effective.

Keywords: marine function zoning; evaluation; indicator system; practice

Since the National Marine Function Zoning Scheme went into effect, 11 coastal provinces, autonomous regions, and municipalities have been approved to implement their

own MFZ. Many coastal provinces started their first round zoning revision. Some cities and counties' MFZs are in their modification procedures.^[1] The Administrative Provisions of Marine Function Zoning (hereinafter referred to as the Provisions) stipulates that the evaluation of MFZ is an important part of MFZ. The establishment of MFZ evaluation system is helpful to prevent MFZ from frequently rectifying after having been approved. The evaluation system is helpful to keep the stability of MFZ. Also it ensures the function zoning to adapt to changes.^[2] With the increasing demands of the recompile of MFZ, the evaluation of MFZ is going to be the premise to ensure MFZ to develop scientifically. The evaluation of MFZ is a new task. Owing to the lack of the concrete evaluation techniques standards, the contents and indicator selection are various in different local governments during the zoning evaluation. There is no standard procedure to evaluate MFZ, which results in the difference in the evaluation outcomes and low reference value. It is hard to choose the proper indicators. And many indicators are hard to quantify. So it is necessary to establish the evaluation standards and evaluation indicator system, regulate the evaluation technical methods, and research on the procedure of evaluation of MFZ. After discussing the implication of the evaluation of MFZ and its evaluation scope, this paper focuses on the selection of the evaluation indicators and the establishment of the evaluation system. Shenzhen's MFZ is taken as an evaluation object to assess the utility of the evaluation indicator system.

1 Definition and the contents of the MFZ evaluation

1.1 Definition of the MFZ evaluation

According to the Provisions, “The department in charge of marine administration under the people's government at or above the county level can make a performance evaluation after MFZ has been approved and implemented for 2 years, and develop the recommendation of a necessary or significant adjustment. The department in charge of marine administration under the people's government at or above the county level can perform the evaluation by its own, or entrust the evaluation to the technical support department.”

According to the development history and the practical situation of MFZ, the MFZ evaluation implicates: 1) the evaluation is an important high-skill job of the MFZ system, and it is the premise and the basis of the rectification of MFZ; 2) ocean administrative departments or the technical support departments should adhere to the principles, such as impersonality, justice, science and truthfulness during the evaluation process, adopt a means of integrating quantitative and qualitative approaches, evaluate and report the MFZ

progress and result, and bring the recommendation of the adjustment of the zoning; 3) instead of evaluating each functional unit or sea using project, the evaluation addresses to the whole, which evaluates the relevant levels of MFZ.

1.2 Determining the contents of zoning evaluation

The evaluation is the premise and the basis of the rectification of MFZ. Since Law of the People's Republic of China on the Administration of Sea Areas, Technical Directives for the Division of Marine Function Zoning (GB/T 17108-2006) (hereinafter referred to as Technical Directives) and the Provisions do not expatiate on the steps and the technical requirements, the basis of the evaluation is relatively weak and it is hard to evaluate MFZ effectively. Until now, a systematic theoretical system of MFZ evaluation has not been set up both at home and abroad.

The performance of MFZ, which can affect the effectiveness of MFZ directly, is an important part of the evaluation contents. It should reflect whether the ocean administrative departments strictly implement MFZ which have been approved, whether the departments regulate the sea using projects, whether the departments rectify the sea using project which was inconsistent with the zoning, whether the departments participate in making the transport, tourism and culturing planning; and whether the departments formulate related administration management system to promote the implementation of MFZ and improve the social impact. The performance of MFZ should ensure the sea using project conform to MFZ. [3]

Resources and environments are the material foundation for the sustainable development. The developing types and the level of the marine economy development are determined by the features of the resources and environments and their bearing capacity. The performance effectiveness of MFZ should reflect whether MFZ can protect the resources and environments, whether MFZ guide appropriate marine development actions and whether MFZ promote the rational distribution of industry. Oceans are essential to the development of the coastal cities and provinces. When there is a contradiction between the using types of land resources and sea resources, the bearing capacity of marine resources and environments is a top priority. The development of the land should ensure the marine health and activity. At the same time, zoning performance effects can reflect the adaptability of MFZ. In other words, it should be considered whether MFZ is adaptable when the implementation situation is normal but the performance effects is relatively low. Therefore, the marine resource environment effect and the social economy effect should also be evaluated. [4]

With the development of the society and the increasing of the active sea using, the natural resources, marine environment, urban orientation, and social economy development which MFZ is based on, have undergone marked changes. According to the Technical Directives, marine function zones are the regions which are divided based on the natural resources, environments, geographical location, and the status of the marine development and utilization, at the same time, taking account of the need of the sustainable national or regional social and economy developing. Marine function zones have the best functions. The marine function zones should be divided under the principles of giving attention to both social and natural attributes at the same time. The reviewing of the dependent condition can reflect whether MFZ is adaptable.^[5] Therefore, it is necessary to recognize the change degrees and the trends of the dependent condition which MFZ is based on.

Based on the above analysis, it's concluded that evaluation parameters should include assessing the general implementation situation of MFZ, the performance effects and the changes of the dependent conditions.

2 Indicator system of zoning evaluation

2.1 The basic design

(1) The indicator system should be able to wholly reflect MFZ, by using the quantitative indicators to analyze, check, supervise and predict the status and trends of MFZ. By evaluating the value, significance and deficiency of MFZ, the evaluation should be able to regulate and manage the marine development, promote the rational distribution of industry, and help to improve the development level of the coastal areas.

(2) In the process of indicator development, the role and effect of indicators in the whole indicator systems should be taken into account. The title, meaning and scale of the indicator should be decided by the property and characters of the content which the indicator reflects. At the mean time, the related data's accessibility should be taken into consideration.

(3) By evaluating the implementation situation, performance effects and changes of dependent condition, the indicators, which affect the marine resource environment and social economy development, are studied. After quantifying the indicators, an evaluation system which is reasonable, operational and complete is established. This evaluation system can help the decision makers and the administrators to have an overall view of the situation macroscopically, and know the effects of MFZ on the regional development. It can

also help the decision makers and the administrators to make a unified planning and promote a balanced development among different regions in the future.

2.2 Evaluation indicators of zoning implementation situation (See Tab. 1)

In order to improve the accuracy of the selected indicators which reflect the main purpose and the implementation situation of MFZ, we should cooperate with major institutional stakeholders and departments in the process of identifying and selecting the evaluation indicators of the zoning implementation. Besides the accessible data, it is necessary to collect the data which need to be further explored. By doing this, the assessment can achieve the desired goal.^[6]

After analyzing the actual situation of the existing MFZ, the implementation situation of MFZ can be evaluated by three aspects which are the adequacy of MFZ, effectiveness of MFZ and public participation respectively. In order to identify the status of MFZ's goal accomplishment and reflect whether the system is implanted, the adequacy of MFZ focuses on the implementation of MFZ, adjustment of the projects which do not comply with MFZ and adjustment of sea using plans etc. The indicators which are related to the adequacy can measure the completeness of the management agencies and the system, the adjustment of the projects which do not comply with MFZ, and the adjustment of the plans of the main sea area's sea use. The effectiveness of MFZ reflects the related situation about complementing and refining management system, including the contradiction resolution mechanism, ecological and environmental protection mechanisms etc. Public participation of MFZ reflects the public support to MFZ, mainly including the stakeholders and social public's participation.

2.3 Evaluation indicators of MFZ performance effect (See Tab. 2)

Marine function zones are the regions which are divided based on the natural resources, environments, geographical location, and the status of the marine development and utilization, at the same time, taking account of the need of the sustainable national or regional social and economy developing.^[5] The effects of MFZ can be evaluated by the following two aspects, environmental effects and socio-economic effects. Resources and environmental effects mainly include environmental quality and status of ecological resources of the area. Socio-economic effects mainly include the socio-economic indicators such as the added value of marine economy, marine development benefits, the number of marine production employees, and the ratio of the added value of marine economy over GDP. Through evaluating the above mentioned indicators, we can deduce the effect which MFZ bring to the resources and environmental quality and the overall level of socio-economic development to determine the reasonableness of MFZ. MFZ's rationality

can be measured by these indicators.

Tab. 1 Evaluation indicators of zoning implementation situation

Standards	Sub-standards	Indicators
Adequate implementation of MFZ	Adequacy of the marine administration and management mechanism	Adequacy of marine administration Completeness of management mechanism
	Project compliance	Proportion of project compliance Proportion of adjusted projects in key sea areas
Effectiveness of MFZ	Contradiction resolution over sea using	Proportion of contradictions that are resolved
	Protection level of ecological resources	Adequacy of ecological protection Proportion of Environmental Impact Evaluation
Public participation in MFZ		Administration departments' awareness of MFZ Stakeholders' awareness of MFZ The public awareness of MFZ

Tab. 2 Evaluation indicators of MFZ performance effect

Standards	Sub-standards	Indicators
Resource and environmental effect of MFZ	Marine environmental quality status	Comprehensive water quality
	Status of marine ecological resources	Frequency of marine disasters Development level of sea area
Socio-economic effect of MFZ		Added value of marine economy Marine development benefits Number of marine production employees The ratio of the added value of marine economy over GDP

2.4 Evaluation indicators of the changes of dependent conditions (See Tab. 3)

In accordance with the provisions which the Technical Directives prescribes, the dependent conditions mainly include the social orientation, natural resources, environmental quality, socio-economic and social needs etc. The dependent conditions are the basis of MFZ. Any change of dependent conditions is bound to affect MFZ's effect. To evaluate MFZ, we must take the overall trend of the future development of the area into account, and at the same time reconcile the marine resource protection with the adjustment of the key zones' functions, and analyze the areas' social orientation, natural resources and environmental condition changes, changes of sea using needs of the marine industry, and the changes in objective conditions of the key areas to evaluate MFZ. It should be noted that it is hard to quantify the change of the social orientation, so we can adopt the method of qualitative analysis.^[7]

During the evaluation process, the national, provincial, urban and county MFZs have their own particular emphases. At the same time, the evaluation should involve other indicators which combine with their own local characteristics. The national MFZ should emphasize particularly on the maintenance of national interests, the national orientation in the world, the industrial development layout and the significant decisions concerning people's livelihood etc. The provincial MFZ should focus on the provincial orientation in the country, advantages in the areas, and unique resources etc. The urban and county MFZs should place more weight on their own orientation in the province, concrete resource environment and social economy features etc. The resource-rich region should focus on the socio-economic growth factors. And the resource-poor area should focus more on indicators of environmental resources.

3 Methods and procedures of MFZ evaluation

3.1 Evaluation methods

MFZs have wide-ranging impact, but some of them which need to be analyzed for research are not possible to quantify. Thus, the quantitative method is mainly adopted, combined with qualitative analysis in the evaluation. The quantitative analysis is used in the evaluation of MFZ's effectiveness and MFZ's implementation situation. The changes of dependent condition are evaluated by using both qualitative and quantitative analysis methods.

Numerical difference among MFZ evaluation values is large and the units of

measurement are not unified. So, non-dimensional quantities of data are necessary. If X_i is the evaluation value of the performance of MFZ, the benefit index is conversed by $(X_i - X_{\min}) / (X_{\max} - X_{\min})$, in which $X_{\max}$ and $X_{\min}$ are indicators of maximum and minimum values of X_i respectively. The cost index is conversed by $(X_{\max} - X_i) / (X_{\max} - X_{\min})$, in which $X_{\max}$ and $X_{\min}$ are indicators of maximum and minimum values of X_i respectively.

Assume X as the assessed value of MFZ, X_i as a single indicator value, W_i as the evaluation index's weight and n as the number of indicators for the evaluation, the evaluation value of MFZ can be expressed as:

$$X = \sum_{i=1}^n W_i X_i$$

where, W_i is determined by the Analytic Hierarchy Process (AHP). The weight value is the key factor which affects the overall evaluation. It is determined by different focuses of MFZs at the concerning levels. By another words, for MFZs of different levels or different regions, there are different weight values. The weight values can not be completely copied.

Tab. 3 Evaluation indicators of the changes of dependent conditions

Standards	Indicators
Changes in social orientation	Changes of the significance of the sea areas Changes in the strategic position of the ocean
Changes in resources	Changes of the harbor resources Changes of the tourism resources
Environmental changes	Surface area changes of various water quality Changes in the quality of the sedimentation
Socio-economic changes	Changes in ratio of marine economy over GDP Changes of the value of cargo-handling capacity/port area Changes in the number of visitors accepted by tourism industry Changes of the commodity output value of fishery value /sea water aquiculture area
Changes of sea using demands of the marine industry	Changes in the demands for the transportation and communications Changes in demands for marine fisheries Changes in demands for coastal tourism Changes in demands for coastal industries

3.2 Evaluation procedures

Evaluation flows are established to ensure an effective and orderly evaluation. The evaluation flows include a management flow and a technical flow. The management flow of the evaluation includes the application procedure, approving to evaluate MFZ, starting to evaluate MFZ, and reviewing the evaluation report etc. The technical flow includes three aspects, that is, data collection and analysis, establishing indicator system and assessing the conclusion (See Fig. 1).

4 Practice of evaluation of MFZ

Shenzhen of Guangdong Province began to implement MFZ system in 2004. The departments and industries have a clear understanding of zoning and comply with MFZ strictly, which regulate the use and the management of the sea area. By comparatively analyzing the data of Environment Bulletin of Marine Resources and other various types of references of marine industry, focusing on the field research on the key areas and marine industries, it's found that Shenzhen is with the following characteristics: (1) as a Special Economic Zone, owing to its own local orientation, Shenzhen's total amount of marine resources requirement and it's development of marine resources continue increasing. But there is no corresponding improvement in the marine environment. The implementation of MFZ has the limited impact on the marine environmental conditions; (2) the marine economic growth rate of Shenzhen is relatively low due to the constraint environmental conditions. The Special Economic Zone does not give full play to the advantage of rapid economic development; (3) with the promoting of Shenzhen's local orientation, Shenzhen is now facing more severe challenges of marine resources and environmental protection. The conditions which the existing MFZ's compilation is based on have changed dramatically.

Through the above contrastive analysis, this evaluation indicator system is adopted to quantitatively evaluate MFZ of Shenzhen by using AHP method. The conclusions of the evaluation are as follows (See Tab. 4. The assessment values are in the range of 0 - 1):

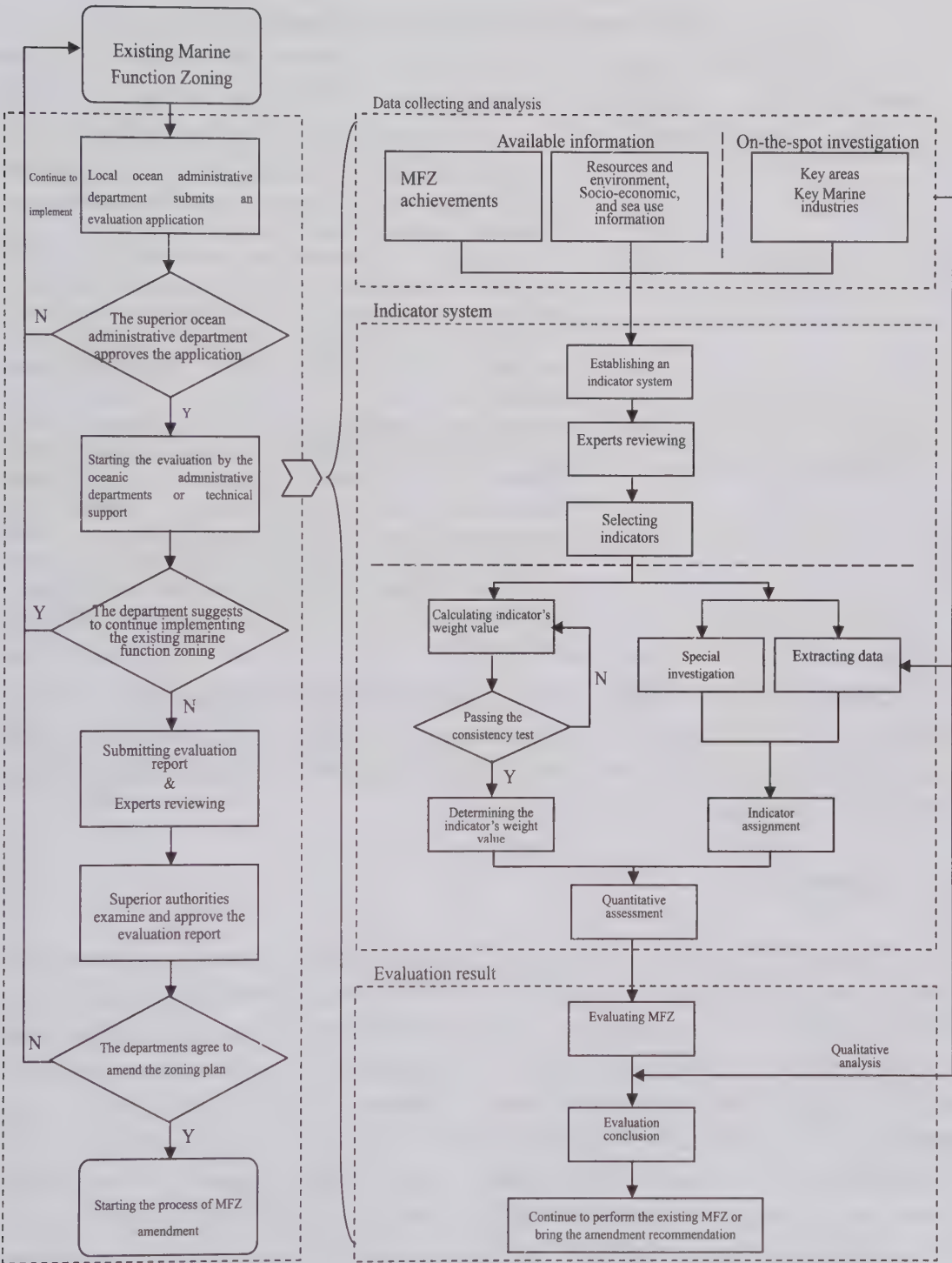


Fig. 1 Management procedure and technical procedure of MFZ evaluation

Tab. 4 Evaluation conclusion of Shenzhen MFZ

Evaluating contents	Evaluation value	Conclusions
Implementation situation of MFZ	0.88	The MFZ system is implemented well in Shenzhen. The evaluation value of the adequacy of MFZ's implementation situation is 0.86. The evaluation value of MFZ effectiveness is 0.90. The evaluation value of the public participation in MFZ is 0.86.
Performance effects of MFZ	0.69	This value shows that Shenzhen's MFZ performance effects are not very good. The evaluation value of the resources and environmental effects is 0.64. The evaluation value of socio-economic effects is 0.81, which shows modest improvement in Shenzhen's marine environment, and MFZ does not play an obvious environmental benefits.
Changes of dependent conditions	0.53	Change value of dependent condition is 0.47. In accordance with the assessed value of the changes of dependent condition = (1 - change value of dependent condition), the evaluation value is 0.53, which shows the changes of dependent conditions are dramatic, and the changes do not comply with the regional development. Among these, the change value of social orientation is 0.58, and change value of environment is 0.43, and socio-economic change value is 0.40, and the change value about the marine industries' demands of the sea is 0.48.

Based on the above research, the results of using the zoning evaluation system to assess MFZ quantitatively are basically same to the conclusions of the relevant information analysis. To a certain extent, this verifies that the established zoning evaluation indicator system is scientific, reasonable and feasible.

5 Conclusions

The practice proves the zoning evaluation indicator system established in this article performs well. This evaluation method which mainly involves quantitative evaluation and is also supplemented by the qualitative analysis, effectively overcomes the limitations of the existing evaluation methods, and reduces the subjectivity of the evaluation criteria and variable degree of deviation. Also it makes a decrease of non-objective factors on the assessment of interference. The methods which consummate the indicators with the local characteristics can reflect the differences in the different regions. The evaluation procedures standardize the zoning evaluation and ensure a smooth and orderly evaluation. The established evaluation system is feasible, and its evaluation results have a relatively high credibility, which is proved to be a well-established evaluation system of effective MFZ.

There are still some deficiencies in the set of evaluation indicators and the weight value determination. Different levels' MFZ need further study to determine the different focuses to evaluate MFZ. Further studies about how to scientifically and reasonably determine the evaluation indicators and the indicator weight of different levels or different regions are necessary to make the evaluation of MFZ more scientific, reasonable, fair and effective.

References

- [1] Lin Ning. Research on the recording system of marine function zoning in China [J]. Ocean Development and Management, 2008, 25(7): 24 - 30;
- [2] A Dong. The foundation of sea use management and marine environmental protection in China—Marine function zoning [J]. Ocean Development and Management, 2000, 17(4): 19 - 22;
- [3] Ge Ruiqing. Theory and practice of marine function zoning [J]. Marine Science Bulletin, 2001, 20(4): 52 - 63;
- [4] Wang Peier. Discussion on the resource-oriented marine function zoning [J]. Journal of Xiamen University (Natural Science), 2004, 43(8): 205 - 210;
- [5] The State Bureau of Quality and Technical Supervision. Technical Directives for the Division of Marine Function Zoning (GB/T 17108—2006) [S]. Standards Press of China, 2006, 1 - 18;
- [6] Lin Ning. A handbook for integrated coastal and ocean management [M]. Beijing: Ocean Press, 2008.
- [7] Peter H R. Evaluation: a systematic approach (7th Edition) [M]. Sichuan: Chongqing University Press, 2007, 71 - 93.

海洋功能区划评估研究与实践

黄南艳^{1,2}, 王 倩², 徐文斌², 林 宁², 李 萍³

(1. 中国海洋大学 海洋环境学院, 山东 青岛 266071; 2. 国家海洋信息中心, 天津 300171;

3. 广东省海洋资源研究发展中心, 广东 广州 510220)

摘 要: 本文在界定海洋功能区划评估含义的基础上, 通过对海洋功能区划的发展和实施情况的分析, 提出了从海洋功能区划执行情况、海洋功能区划执行效果和海洋功能区划依赖条件变化三方面构建海洋功能区划评估指标体系的基本构架, 探讨了海洋功能区划评估指标选取应当遵循的基本设计思想。其中, 海洋功能区划执行情况主要涉及海洋功能区划概况、海域开发利用概况、海洋功能区划的目标实现情况、制度落实情况和社会参与情况等指标; 海洋功能区划执行效果主要从规范海域开发秩序、保护海洋资源环境、促进海洋经济发展等方面的成效和存在的问题进行评估; 海洋功能区划依赖条件变化主要从社会经济条件变化、海洋产业用海需求变化、自然资源条件变化、海洋环境条件变化等指标进行评估, 衡量其变化程度。根据国家级、省级和市县级海洋功能区划编制内容的不同, 提出了不同级别海洋功能区划评估的侧重点, 制定了评估流程。在此基础上, 运用定量评估为主, 定性分析为辅的方法, 以深圳市海洋功能区划为例, 将海洋功能区划评估指标应用到海洋功能区划评估的实践工作中, 检验了海洋功能区划评估指标体系的科学性、合理性和可行性, 指出区划评估仍需研究的问题, 对深入开展海洋功能区划评估具有一定的参考意义。

关键词: 海洋功能区划; 评估; 指标体系; 实践

Using factor analysis on the comprehensive evaluation of oil pollution in the Haihe river basin

DAI Yuan-yuan¹, SONG Wen-ping¹, ZHENG De-bin¹, WANG Xiao-yu¹, SHANG Xiao-di¹, WANG Li-ping¹, MA Chao¹, ZHANG Yang¹, SUN Xue-liang²

1. *Tianjin Bohai Sea Fisherise Research Institute, Bohai Sea Fisheries Research Center, Chinese Academy of Fishery Sciences, Tianjin 300457, China*

2. *Tianjin Key Laboratory of Aquatic Ecology and Aquaculture, Department of Fisheries Science, Tianjin Agricultural College, Tianjin 300380, China*

Abstract: Selecting six indexes of pH, DO, COD, BOD5, ammonia nitrogen and petroleum hydrocarbons in Haihe River Basin of four seasons in 2012 - 2013 for factor analysis, applying Water Quality Pollution Index (API) to evaluate DO, COD, BOD5 and ammonia nitrogen, aims for systematic evaluation to water quality of Haihe River Basin. The results showed that two stations of BJ1 and HB2 were the IV type of water, others were the V type; Water Quality Pollution Index (API) was 1.44, which illustrated Haihe River Basin in the state of contamination that the degree of pollution exceeded the standard of functional areas. Factor Analysis explained that between COD, DO and NH₃-N were significant difference ($P < 0.05$); principal component analysis showed that, in addition to pH and BOD5, the other indicators were above 0.70; the contribution rate of COD, DO, NH₃-N and TPH were higher, petroleum hydrocarbons was 100%, it can be considered that the waters type of pollution was organic pollution, and petroleum hydrocarbon contamination was more prominent.

Keywords: Haihe river basin; Petroleum hydrocarbons; factor analysis; comprehensive evaluation

Haihe River Basin was one of seven major river which had drainage area extensively^[1]. With the rapid development of urban industrial and population growth, the daily discharge of sewage and industrial effluent most untreated directly into rivers and lakes^[2], the urban sewage and waste matter emissions were one of the main sources for petroleum hydrocarbon contamination which made water quality not only deteriorated, so that impacting the development of aquaculture^[3]; also affected the production and living environment^[4]. Currently on petroleum hydrocarbon contamination of Haihe River Basin

were more studied, about distribution and sources of polycyclic aromatic hydrocarbons in Haihe River Basin [3, 5-7] and Bohai Bay [2, 4]. Therefore, this paper selected six water quality indicators of Haihe River Basin, and comprehensive evaluated water quality based on factor analysis.

1 The sources of data

The datas in this paper were from the system of water quality automatic real-time monitoring for surface water in 2012 - 2013 which including pH, DO, COD, BOD₅, ammonia nitrogen and petroleum hydrocarbons.

2 Figure of stance

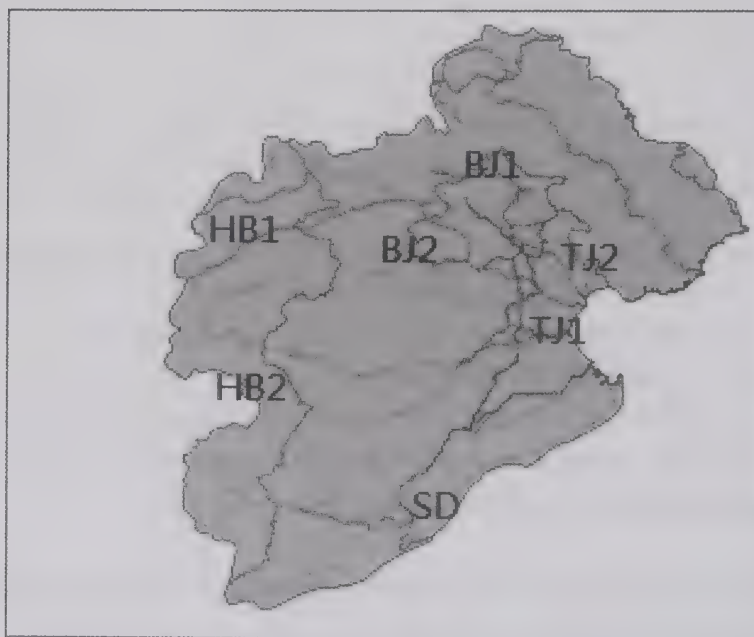


Fig. 1 Haihe River Basin Basin station bitmap

3 Infusions and analysis

3.1 Index for water

Collectting and summarizing the data of four seasons from 2012 - 2013, the data were the average of stations $\pm$ standard deviation ($M \pm S$) in Tab. 1.

Tab. 1 The monitoring indicators of each station

The station	Latitude and longitude	The main indicators for monitoring (Unit: mg/L)					
		pH	BOD ₅	DO	COD	NH ₃ -N	TPH
TJ1	E117°11'21.9" N39°08'22.5"	7.86±0.633	8.28±1.021	5.62±4.159	6.55±2.090	2.29±1.538	8.91±1.009
TJ2	E117°44'54.2" N40°01'21.3"	7.81±0.093	2.85±0.489	11.31±1.875	2.22±0.507	0.35±0.067	12.80±1.633
BJ1	E117°17' N40°47'	8.20±0.161	4.04±0.208	9.89±1.236	2.14±0.324	0.13±0.047	2.57±0.605
BJ2	E115°42'55" N40°04'10"	8.17±0.174	9.00±1.102	10.17±2.037	2.84±0.384	0.15±0.046	21.33±2.010
HB1	E115°32'52" N40°20'27"	7.55±0.496	7.95±0.337	7.64±1.973	4.47±1.157	1.09±0.577	45.30±5.224
HB2	E113°59'34" N38°19'06"	8.26±0.321	2.46±0.076	9.89±1.127	1.97±0.150	0.11±0.052	3.49±0.341
SD	E115°31' N36°54'	7.88±0.506	6.32±0.051	2.10±0.403	9.90±3.760	4.43±3.405	63.90±5.669

3.2 Statistical analysis

3.2.1 Water Quality Pollution Index

Water Quality Pollution Index (API) was an arithmetic mean of the number of water quality index, which selecting eight indicators of permanganate index, BOD₅, COD, ammonia nitrogen, petroleum, phenol, total phosphorus, total mercury for the parameter. Water quality index which determined the degree of pollution relatively which the corresponding function requestion and evaluated the degree of pollution. Combined with the actual situation, we selected four indicators for evaluation: BOD₅, COD, DO and ammonia nitrogen.

Specific formula:

$$P=\frac{1}{n}\sum P_i=\frac{1}{n}\sum \frac{C_i}{S_i}$$

Among: C_i was the measured values; S_i was the quality standard values.

Tab. 2 The quality standard in surface water (mg/L) GB3838-2002

Classification	COD	BOD ₅	NH ₃ -N	TPH	DO
	≤	≤	≤		≥
I	2.00	3.00	0.15	0.05	7.50
II	4.00	3.00	0.50	0.05	6.00
III	6.00	4.00	1.00	0.05	5.00
IV	10.00	6.00	1.50	0.50	3.00
V	15.00	10.00	2.00	1.00	2.00

Tab. 3 The Level table of Pollution Index

	I		II		III		IV		V	
	C _i	P _i	C _i	P _i	C _i	P _i	C _i	P _i	C _i	P _i
BOD ₅	3	0.75	3	0.75	4	1	6	1.5	10	2.5
COD	2	0.33	4	0.67	6	1	10	1.67	15	2.5
DO	7.5	1.5	6	1.2	5	1	3	0.6	2	0.4
NH ₃ -N	0.15	0.15	0.5	0.5	1	1	1.5	1.5	2	2

Note: As level III of water standard in GB3838-2002 to accomplish the pollution Index level table.

Tab. 4 The analysis results of monitoring indicators for all stations

The station	BOD ₅		COD		DO		NH ₃ -N		The total level
	P _i	Level	P _i	Level	P _i	Level	P _i	Level	
TJ1	2.070	V	1.323	IV	1.124	III	2.290	V	V
TJ2	0.713	III	2.240	V	2.262	I	0.350	II	V
BJ1	1.010	IV	1.185	IV	1.978	I	0.130	I	IV
BJ2	2.250	V	1.135	IV	2.034	I	0.150	I	V
HB1	1.988	V	1.973	V	1.528	I	1.090	IV	V
HB2	0.615	II	1.245	IV	1.978	I	0.110	I	IV
SD	1.580	V	1.063	IV	0.420	V	4.430	V	V
ΣP _i	10.225		10.165		11.324		8.550		
P	1.46		1.45		1.62		1.22		1.44

Tab. 5 The standard of criteria

P	Judgment result
P≤0.8	Qualified, indicating that water quality objectives can basically achieve the appropriate functional criteria, individual exceeded 1 times
0.8<P≤1.0	Basically qualified, a small number of indicators over the appropriate category standard, but there is no obvious damage to water
1.0<P≤2.0	Pollution, most indicators than the corresponding standard function of water will be restricted
P>2.0	Heavy pollution, the total number has more than 1 times of standard, some indicators over several times, and water function subject to serious harm.

According to the results of Tab. 4, P is 1.44. In Tab. 5 shows that most indicators have exceeded the corresponding national standards, water function area will be restricted.

3.2.2 Factor analysis

Factor analysis is to study the dependencies of internal variable, which to find the most reflection of water pollution and orthogonal factor, which to evaluate the current situation of water pollution. We selected four indicators for evaluation: pH, BOD₅, COD, DO, ammonia nitrogen and TPH.

Tab. 6 Correlation Matrix^a

		pH	BOD ₅	COD	DO	NH ₃ -N	TPH
Correlation	pH	1.000	-.353	.365	-.425	-.398	-.570
	BOD ₅	-.353	1.000	-.420	.452	.333	.421
	COD	.365	-.420	1.000	-.984	-.974	-.721
	DO	-.425	.452	.452	1.000	.991	.755
	NH ₃ -N	-.398	.333	.333	.991	1.000	.739
	TPH	-.570	.421	.421	.755	.739	1.000
Sig.(1-tailed)	pH		.219	.210	.171	.188	.091
	BOD ₅			.174	.154	.232	.173
	COD				.000	.000	.034
	DO					.000	.025
	NH ₃ -N						.029
	TPH						

a determinant = 5.50E-007, Between COD, DO and NH₃-N were significant difference (P <0.05)

Tab. 7 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of sampling adequacy.	.436
Bartlett's Test of Approx. Chi-Square	45.641
Sphericity df	15
Sig.	.000

The above datas test by Bartley examination ($P<0.05$) in Tab. 7, so can use factor analysis in this study.

Tab. 8 Communalities

	Initial	Extraction
pH	1.000	.342
BOD ₅	1.000	.305
COD	1.000	.893
DO	1.000	.939
NH ₃ -N	1.000	.890
TPH	1.000	.740

Extraction Method: Principal Component Analysis.

In Tab. 8 means that the extracted information for each variable, in addition to the pH and BOD₅, other indicators are more than 0.70.

Tab. 9 Contribution rate of all indicators

Component	Eigenvalues	Contribution rate%	Cumulative Contribution rate%
pH	4.109	68.490	68.490
BOD ₅	.908	15.127	83.617
COD	.678	11.304	94.921
DO	.282	4.699	99.620
NH ₃ -N	.023	.379	99.999
TPH	3.389E-5	.001	100.000

Tab. 9 shows that the main cause of pollution in this sea, which considering the contribution rate of COD, DO, NH₃-N and TPH were higher and TPH is 100%, so that the type of pollution in this sea belongs to the organic pollution, and petroleum hydrocarbon contamination was more prominent.

4 Conclusions

(1) The results showed that two stations of BJ1 and HB2 were the IV type of water, others were the V type; Water Quality Pollution Index (API) was 1.44, which illustrated Haihe River Basin in the state of contamination that the degree of pollution exceeded the standard functional areas.

(2) Factor Analysis explained that between COD, DO and $\text{NH}_3\text{-N}$ were significant difference ($P < 0.05$), the contribution rate of COD, DO, $\text{NH}_3\text{-N}$ and TPH were higher, petroleum hydrocarbons was 100%, it can be considered that the waters type of pollution was organic pollution, and petroleum hydrocarbon contamination was more prominent.

(3) Haihe River Basin had potential ecological risk.

Acknowledgements

We would like to thank Dong Yu-bo for helpful advice. This research is supported by the Key Laboratory of Marine Oil Spill Identification and Damage Assessment Technology, State Oceanic Administration (201214).

References

- [1] Ge Yu, Jing Chen, Xueqing Zhang, et al. Comprehensive analysis of an ecological risk assessment of the Daliao River estuary, China [J]. Environ. Monit. Assess., DOI 10.1007/s10661-013-3065-y.
- [2] Qiuying Chen, Jingling Liu, Kin Chung Ho, et al. Development of a relative risk model for evaluating ecological risk of water environment in the Haihe River Basin estuary area. Science of The Total Environment [J], 2012,(420):79 - 89.
- [3] Ning Jing Hu, Xue Fa Shi, Peng Huang. Polycyclic aromatic hydrocarbons in surface sediments of Laizhou Bay, Bohai Sea, China [J]. Environ. Earth Sci., 2011, 63:121 - 133.
- [4] Cheng Y M, Zhu L Y, Tian S Y, et al. Distribution and sources of polycyclic aromatic hydrocarbons in surface sediments from the Haihe River and the Bohai Sea [J]. Acta Scientiae Circumstantiae, 2009, 29(11): 2 420 - 2 426.
- [5] LUO Xian-xiang, ZHANG Qiu-yan, YANG Jian-qiang. Total Petroleum Hydrocarbon Contamination Characteristics in Shuangtaizi EstuaryWetlands [J]. Research of Environmental Sciences, 2010, 23(4): 437 - 444.
- [6] GUO Liang-Bo, JIANG Wen-Sheng, LI Feng-Qi. Environmental Capacity Calculation of COD and PAHs in the Bohai Sea [J]. Journal of Ocean University of China, 2007, 37 (2): 310 - 316.

- [7] Jiang Wensheng. A three dimensional modelling of suspended particulate matter dynamics in the Bohai Sea [J]. Berichte aus dem Zentrum fur Meeresund Klimaforschung der Universitat Hamburg, Reihe B, Ozeanographie, 1999, 34: 1 - 104.

因子分析在海河流域石油类污染综合评价中的应用

戴媛媛¹, 宋文平¹, 郑德斌¹, 汪笑宇¹, 尚晓迪¹, 王立平¹,
马超¹, 张阳¹, 孙学亮²

(1. 天津渤海水产研究所 中国水产科学院渤海水产研究中心, 天津 300457;

2. 天津农学院水产科学系 天津市水产生态及养殖重点实验室, 天津 300380)

摘要: 基于因子分析对 2012~2013 年海河流域 pH、DO、COD、BOD₅、氨态氮和总石油烃等 6 项水质指标的监测数据进行统计, 并对其中四项指标进行水污染综合指数评估, 旨在对海河水质进行较为系统的评价。结果显示, BJ1 和 HB2 两个站位水质属于 IV 类标准, 其余各站位均为 V 类; 各站位综合评价结果得到海河流域指数为 1.44, 说明海河流域处于污染状态, 其污染程度超过该流域功能区标准。因子分析发现, COD、DO 和 NH₃-N 之间差异显著 ($P < 0.05$); 主成分分析显示, 除 pH 和 BOD₅ 外, 其余指标都在 0.70 以上; COD、DO、NH₃-N 和 TPH 的贡献率较高, 其中总石油烃的贡献率为 100%, 因此可以认为该海域的污染类型属于有机污染, 且石油烃污染较为突出。

关键词: 海河流域; 总石油烃; 因子分析; 综合评价

Source analysis and ecological risk assessment for heavy metals in the sediments of the Yangshan Deepwater Harbor in autumn and winter

YE Ran, QIN Ming-li, CUI Yong-ping, GU Hong-wei, YE Xian-sen*

Marine Environmental Monitoring Centre of Ningbo, State Oceanic Administration, Ningbo, 315012, Zhejiang Province, China

Abstract: Temporal and spatial variations of concentrations of heavy metals including mercury (Hg), zinc (Zn), lead (Pb), arsenic (As), copper (Cu), and cadmium (Cd) in the sediments of the Yangshan Deepwater Harbor were determined based on 6 cruises in autumn and winter, respectively, from 2010 to 2013. The results demonstrated that the overall concentrations of heavy metals were low and distributed in uniform patterns. The concentrations of Hg, Zn, Pb, and Cd in autumn were significantly higher than those in winter with small fluctuations for As and Cu in terms of seasonal variations. Results of factor analysis showed that Pb, Cd, and Zn were derived from inland industrial and shipping discharges as well as the degradation of organic pollutants in marine environment. While agricultural pollutions, cargo shifting and construction debris from reclamation projects contributed to the sources of Cu, As, and Hg. Ecological risk assessment by Mean Sediment Quality Guideline Quotient (SQG-Q) revealed that the degree for eco-risk of the sediments was low-and-moderate in autumn, higher than that in winter. Hg and Cu were the dominant eco-risk factors. The results of Index of geoaccumulation (I_{geo}) showed that the whole sites of the sea area were barely influenced by Hg, As, Zn, and Pb, and the extents of Cd and Cu contaminations were in low grade. Contamination degree of all the six heavy metals could be ranked as the following: $Cd > Pb > Zn > Hg > As$. According to the results of integrated score of factor analysis, the contamination degree for heavy metals in sediments of the Yangshan Deepwater Harbor was low, despite sites No.5, No.4 and No.3, which were heavily contaminated compared with others.

Keywords: Yangshan Deepwater Harbor; sediment; heavy metals; ecological risk; contamination grade

The Yangshan Deepwater Harbor is the first island-based port in China and was located at Yangshan Island Chain, Shanghai, to the east of the Hangzhou Bay and the

southeast of Yangtze River Estuary respectively. It is approximately 32 km northwest of Luchaogang, the southern entrance of Shanghai by the linkage of the East China Sea Bridge and about 90 km south of Beilun Port, Ningbo and 83 km east of the international sea-route via the Huangze Waterway. As the closest deepwater harbor to Shanghai and the important maritime traffic interchange of the East China Sea, waters off and the adjacent sea areas to the Yangshan Deepwater Harbor would probably be contaminated by pollutants such as oil, heavy metals when cargos are charged/discharged to/from ships or inevitably leaked into marine environment through navigations^[1]. However, with the continuous development of petrochemical industries standing in the northern side of the Hangzhou Bay, waste containing heavy metals discharged from the outlets constantly diffused into water under physical-chemical mechanism and transformed into organic compounds carrying much more intensive toxicity under certain conditions, and finally degraded into sedimentary phase^[2]. Moreover, heavy metals would be released from sediments diffusing into the aqueous phase again and hence become the secondary pollutants to pose biological toxicity upon hydrobios^[3, 4] and consequently would affect the marine ecological environmental quality.

The threshold of pollutants in sediments which could bring biological toxicity and other negative effects could be identified by Mean Sediment Quality Guideline Quotient (SQG-Q) of which the chemical and biological data sets were statistically analyzed based on sets of the studies of sediments in the ocean. SQG-Q enabled the results of the ecological risk assessment for heavy metals to high credibility and low uncertainty, mainly due to the followings: (1) SQG-Q took mean contamination degree caused by several heavy metals into consideration compared with other methods that only remained single index. (2) Latest revised reference value has been applied to SQG-Q^[5]. Long and Macdonald have exported Probable Effect Level/Threshold Effect Level Guideline (PEL/TEL) from the Biological Effects Data Base for Sediments (BEDS) which could quickly identify heavy metals featuring potential biological toxicity and has been generally applied to marine sediment contamination assessment in Europe and US^[6-8].

In this context, we focused both on source analysis and ecological risk assessment for heavy metals in the sediments of the sea area adjacent to Yangshan Deepwater Harbor with the former using factor analysis (FA) and the latter through index of geoaccumulation (I_{geo})^[9] and the integrated score of factor analysis (ISFA) based on 6 cruise investigations. We expected that the results of our study could be beneficial to the sustainable development and management for marine ecological environmental conservation.

1 Materials and methods

1.1 Study area

12 sediment sampling sites were disposed in the study area in autumn and winter from 2010 to 2013 (Fig. 1).

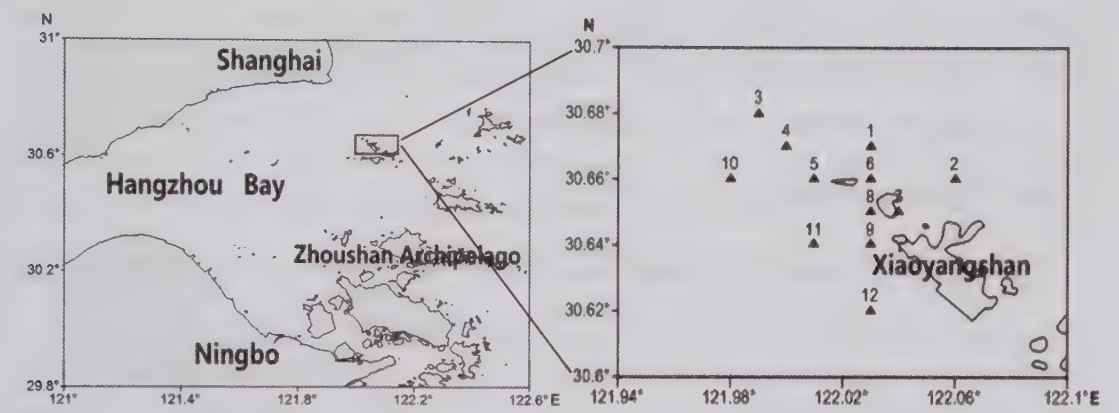


Fig. 1 Sampling sites in the sea area

1.2 Samples measurements

All the samples were in accordance with *The Specification for Marine Monitoring (GB17378.5-2007)* of China including sampling and measurements and quality control. Among them, Cu, Pb, Cd were determined by non-flame atomic absorption spectrophotometry and Zn were determined by flame atomic absorption spectrophotometry. Atomic fluorescence spectrometry was used for the determination of Hg and As, while total organic carbon (TOC) were determined by TOC analyzer and ultraviolet spectrophotometry for oil.

1.3 Ecological risk assessment for heavy metals

1.3.1 Identification and assessment of biological toxicity for heavy metals

Ecological risk assessment for heavy metals is calculated by the formula,

$$SQG - Q = \frac{\sum_{i=1}^n PEL - Q_i}{n}, \quad PEL - Q_i = \frac{C_i}{PEL_i};$$

Where $PEL - Q_i$ is the integrated probable effect level index for the i th pollutant, and C_i is the concentration for the i th pollutant, and PEL_i refers to the probable effect level for the

i th pollutant. When $SQG-Q \leq 0.1$, the area is ecologically contaminated in low degree and moderate degree when $0.1 < SQG-Q < 0.5$. Providing $0.5 \leq SQG-Q \leq 1.5$ and $SQG-Q \geq 1.5$, it indicates that the area is ecologically contaminated heavily and intensively, respectively.

Identification of biological toxicity for heavy metals is based on PEL/TEL Guideline (see the reference values in Tab. 5), of which PEL stands for probable effect level while TEL represents for threshold effect level. When the concentration of pollutants is $< TEL$ or between TEL and PEL, biological toxicity will occur seldom and occasionally, respectively. It appears frequently only when the concentration of pollutants is $> PEL$.

1.3.2 Assessment for heavy metals contamination

(a) Index of geoaccumulation (I_{geo})

Assessment for heavy metal contamination is calculated by:

$$I_{geo} = \log_2 \left(\frac{C_n}{K} \times BE_n \right);$$

Where I_{geo} is the index of geoaccumulation, and C_n is the concentration for heavy metals, and K is a constant (usually refers to 1.5), and BE_n is the geochemical background values for heavy metals. For our targeted sea area concentrating in the inshore area of the East China Sea, we took the results of heavy metals in sediments in the East China Sea that Wang et al. have done in 2003 as the background values were 10.52, 66.1, 20.27, 0.053, 0.092, 16.6 for Cu, Zn, Pb, Cd, Hg and As (unite: mg/kg), respectively^[10]. Criteria for I_{geo} shows as the following: $I_{geo} < 0$, $0 < I_{geo} < 1$, $1 < I_{geo} < 2$, $2 < I_{geo} < 3$, $3 < I_{geo} < 4$, $4 < I_{geo} < 5$, $I_{geo} > 5$ are corresponding to the contamination degree described as clear, slightly contaminated, between clear and slightly contaminated, moderately contaminated, between moderately contaminated and heavily contaminated, heavily contaminated and intensively contaminated, respectively.

(b) Integrated score of factor analysis

We also used integrated score of factor analysis (ISFA) in order to verify the results evaluated by I_{geo} . The higher the ISFA is, the heavier the contamination degree.

$$F = A_1 \times f_1 + A_2 \times f_2 + \dots + A_i \times f_i, (i=1, 2, \dots, i);$$

Where F is the integrated score of each site, and A_i is the weighting of each factor and f_i refers to the scored coefficient of each factor.

2 Results and discussions

2.1 Temporal and spatial differences of the concentration for heavy metals

2.1.1 Temporal and spatial distributions for heavy metals in waters

Results of contents for heavy metals in waters of all the 6 cruises were as the following: Zn: 19.3 - 31.7 $\mu\text{g/L}$, Cu: 1.4 - 5.9 $\mu\text{g/L}$, Pb: 0.29 - 2.00 $\mu\text{g/L}$, Cd: 0.091 - 0.260 $\mu\text{g/L}$ (As and Hg were not determined due to certain reasons). Obviously, contents for heavy metals in waters were low and below the second level of the *Sea Water Quality Standard (GB 3097-1997)* of China with Zn, Cu slightly higher in autumn than those in winter, and Pb, and Cd acted no significant differences in seasonal variations.

2.1.2 Temporal and spatial distributions for heavy metals in sediments

Results of contents for heavy metals in sediments of all the 6 cruises were shown in Tab. 1, of which Zn and Pb fluctuated strongly from 48.7 to 123.4 mg/kg and 12.4 to 44.7 mg/kg, 75.4 mg/kg and 28.2 mg/kg on average, respectively, and Hg and Cd varied slightly from 0.038 to 0.060mg/kg and 0.08 to 0.26 mg/kg, 0.046 and 0.14 mg/kg on average, respectively. Generally, contents for heavy metals in sediments in the targeted sea area were low, and the mean and maximum values for all the 6 heavy metals were below the first level of *Marine Sediment Quality (GB18668-2002)*of China. We found that concentrations of Hg, Zn, Pb, Cd were slightly higher in autumn than those in winter, and small fluctuation for As and Cu in seasonal variations, which was probably due to the construction progress of reclamation projects around Yangshan Deepwater Harbor in autumn, was busier than that in winter which resulted in the sedimentation of heavy metals from dredged materials. We also demonstrated that concentrations for all the heavy metals in the 12 sampling sites within 6 cruises showed no significant differences ($P>0.05$) and distributed in uniform patterns which accorded with the findings reported by Zhang ^[11].

2.2 Source analysis

We used factor analysis (FA) for the study of probable source for heavy metals in the targeted sea area by statistical software, SPSS (Ver.21.0). Two major steps for FA: (1) Pre-test for the feasibility through KMO Test and Bartlett Test against the sediment data we determined (including Hg, Zn, Pb, As, Cu, Cd, TOC and oil). Herein, the values of KMO Test and Bartlett Test were 0.742 and below 0.001 which were both available. (2) Start the remaining program ^[12].

Results of FA (see Tab. 2 and Fig. 2) inferred that the first two components could

represent for the majority information of all the data sets as the total contribution rate of accumulative variance for the 8 factors was 75.710%. F1 contributed 50.229 % to the total contribution rate of accumulative variance featuring high positive loading on Pb, Cd, Zn. For the targeted sea area functioned as an area of port and shipping according to the *National Marine Function Regionalization* of China, a large amount of ships would inevitably discharge waste into marine environment during navigations, thus it would be contaminated by Pb which was generally viewed as the source of diesels and the diesel-driven engine ^[13, 14]. Liu ^[15] and Li ^[16] have done the workshop concerning the sources of Zn and Cd, from which the results demonstrated that the former mainly originated from residual remaining zinc during the process of mining and manufacturing for industrial utilities and the latter commonly derived from waste discharged from metallurgic plants, electroplating factories, respectively. Given the fact that there were Jiaying Electric Power Plant, Qinsan Nuclear Electric Power Plant as well as petrochemical industrial parks in Jinshan District, Shanghai, standing in the northern side of the Hangzhou Bay, and the geographical position of Yangshan Deepwater Harbor was influenced by the runoff from Qiantang River and Yangtze River, thus, untreated waste discharged from industrial outlets could flow to the targeted sea area because of the southeastward direction of Changjiang Diluted Water in autumn and winter ^[17], which was in accordance with the results that Jin has done in the Hangzhou Bay ^[18]. Moreover, metallic ions could be released from organic pollutants during the process of degradation in the sea water ^[19] as there was high positive loading on TOC and oil in F1 with the coefficients referring to 0.785 and 0.693 which inferred that these two variables were the main compounds for Pb, Cd and Zn in sediments. Summarily, F1 controlled the source of Pb, Cd, Zn and partial organic pollutants which were contributed by inland industrial and shipping discharge as well as the degradation of organic pollutants in marine environment.

F2 contributed 25.480% to the total contribution rate of accumulative variance featuring high positive loading on Cu, As, Hg. Given the dense population and high degree of agricultural activities in the Yangtze River Delta, hence, it indicated that As and Cu may attribute to the agricultural pollution for these two elements commonly remained in pesticide and fertilizer and barely existed in physical environment as simple substance ^[20]. Meanwhile, both construction debris from reclamation projects and construction material remaining Cu, As and Hg would inevitably leak into marine environment when cargo charged/discharged to/from ships. Similarly, Tong ^[21] has revealed that waters off most transportation ports in coastal areas would be contaminated by Hg to various degrees. For the results of our study, we found that total mean values of site No.5 of Hg, As and Cu within all the 6 cruises were 0.050, 4.49 and 25.9 mg/kg, respectively which topped all the 12 sites, so we were convinced that these 3 mentioned heavy metals in sediments,

especially for Hg, mainly derived from ports during the process of cargo shifting (site No.5 was the closest to reclamation projects in Xiaoyangshan Island). Besides, matrix of Pearson coefficients (Tab. 3) has also illustrated that Cu, As and Hg may have the similar source for there was significant pairwise correlation among these 3 heavy metals. From all above, we remained that F2 represented source of heavy metals in sediments from agricultural pollution, cargo shifting and construction debris from reclamation projects for Cu, As and Hg.

Tab. 1 Concentrations of heavy metals in sediments

Sampling date	Statistical items	Unit: mg/kg					
		Hg	As	Zn	Pb	Cd	Cu
Autumn in 2010	Min	0.040	2.89	67.0	34.1	0.14	15.6
	Max	0.060	3.49	82.8	43.1	0.23	26.1
	Mean	0.051	3.22	75.2	38.9	0.18	20.8
Winter in 2011	Min	0.038	3.88	71.6	16.9	0.13	17.3
	Max	0.051	4.52	87.5	29.5	0.18	27.0
	Mean	0.044	4.19	77.3	22.4	0.16	21.0
Autumn in 2011	Min	0.039	3.90	74.9	16.4	0.08	10.3
	Max	0.050	4.54	102.3	42.4	0.22	33.7
	Mean	0.044	4.23	87.5	30.4	0.14	23.2
Winter in 2012	Min	0.041	4.16	63.3	18.4	0.11	23.2
	Max	0.049	4.84	80.0	30.0	0.17	28.5
	Mean	0.046	4.42	72.7	25.2	0.13	25.5
Autumn in 2012	Min	0.047	4.82	62.5	20.1	0.08	16.6
	Max	0.052	5.12	123.4	44.7	0.26	30.6
	Mean	0.050	4.97	79.9	32.4	0.13	25.1
Winter in 2013	Min	0.039	4.43	48.7	12.4	0.09	12.3
	Max	0.047	5.17	69.2	26.9	0.15	24.6
	Mean	0.043	4.78	59.5	19.8	0.11	19.1

Tab. 2 Results of Factor Analysis

	Eigen-value	Contribution rate of variance /%	Total contribution rate of accumulative variance /%	Zn	Pb	Cd	Cu	As	Hg	TOC	oil
F1	4.018	50.229	50.229	0.812	0.810	0.790	0.487	0.379	0.505	0.785	0.693
F2	2.038	25.480	75.710	-0.411	-0.202	-0.354	0.721	0.854	0.774	-0.296	-0.223

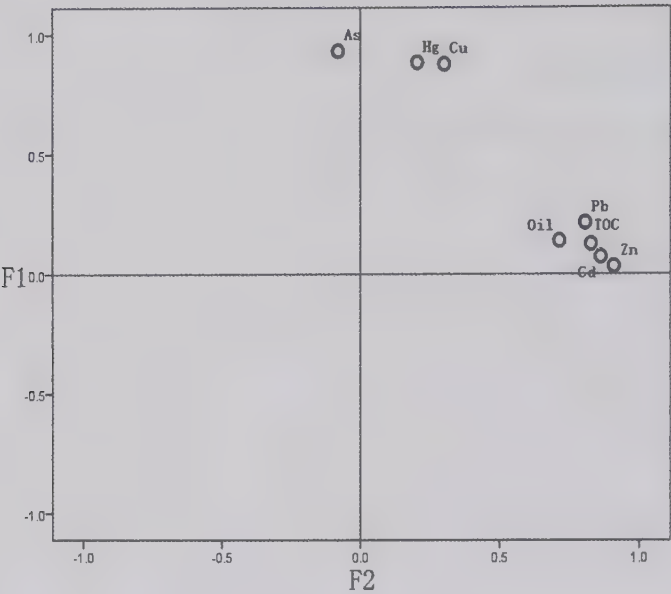


Fig. 2 Two-dimensional loading plots of factors

Tab. 3 Matrix of Pearson coefficients

	Zn	Pb	Cd	Cu	As	Hg
Zn	1					
Pb	0.691	1				
Cd	0.714	0.789	1			
Cu	0.310	0.447	0.316	1		
As	0.006	0.061	0.012	0.752	1	
Hg	0.177	0.394	0.236	0.740	0.718	1

2.3 Ecological risk assessment

2.3.1 Identification and assessment of biological toxicity for heavy metals

Results of ecological risk assessment for heavy metals in Tab. 4 demonstrated that indices of SQG-Q ranged slightly from 0.1 to 0.5 featuring low-and-moderate degree ecological risk in autumn which was higher than that in winter.

The PEL/TEL Guideline was applied to the identification of biological toxicity for heavy metals, and findings (Tab. 5) showed that concentrations of Hg and Cu were between TEL and PEL of all 12 sites; Pb were all below TEL excluding sites No.4, No.5, No.12 which were between TEL and PEL; As, Zn and Cd were below TEL in all 12 sites. Hence, we thought that biological toxicity triggered by Hg, Cu in all the 12 sites and Pb in a

few sites (accounting for 16.7%) would seldom occur, which meant there would be little adverse impact on sedimentary environments. And biological toxicity triggered by Pb in the majority of sites (accounting for 83.3%) and As, Zn, Cd in all 12 sites would barely appear. Consequently, Hg and Cu were identified as the major eco-risk factors.

Tab. 4 Indices of SQG-Q in different sites of each cruise

Sites	Cruises					
	Autumn	Winter	Autumn	Winter	Autumn	Winter
	in 2010	In 2011	in 2011	In 2012	in 2012	In 2013
1	0.17	0.14	0.17	0.16	0.17	0.13
2	0.15	0.14	0.16	0.14	0.16	0.15
3	0.18	0.15	0.17	0.15	0.17	0.14
4	0.17	0.15	0.23	0.16	0.18	0.15
5	0.17	0.15	0.22	0.17	0.18	0.16
6	0.16	0.14	0.19	0.15	0.15	0.10
7	0.16	0.14	0.17	0.17	0.18	0.12
8	0.17	0.15	0.17	0.14	0.20	0.13
9	0.18	0.14	0.16	0.15	0.14	0.13
10	0.17	0.14	0.14	0.15	0.18	0.13
11	0.17	0.15	0.15	0.17	0.19	0.13
12	0.17	0.15	0.16	0.15	0.18	0.13

Tab. 5 Results of the identification of biological toxicity for heavy metals

Sites	Unit: mg / kg					
	Hg	As	Zn	Pb	Cd	Cu
1	0.046	4.20	74.2	27.9	0.14	23.9
2	0.046	4.32	69.9	27.4	0.16	22.1
3	0.043	4.15	76.4	25.9	0.14	22.5
4	0.046	4.18	78.2	30.5	0.15	21.7
5	0.050	4.49	79.7	31.8	0.17	25.9
6	0.049	4.34	77.9	25.7	0.11	19.6
7	0.049	4.34	75.7	28.3	0.13	21.9
8	0.047	4.22	82.6	27.6	0.13	22.2
9	0.046	4.22	72.1	26.0	0.14	21.1
10	0.048	4.31	72.4	26.0	0.13	21.8
11	0.045	4.35	73.3	29.8	0.14	23.9
12	0.044	4.46	71.7	30.2	0.14	22.4
Values of TEL	0.013	7.24	124	30.2	0.68	18.7
Values of PEL	0.7	41.6	271	112	4.21	108

2.3.2 Assessment for heavy metal contamination

Results of I_{geo} (Tab. 6) inferred that the targeted sea area was nearly not contaminated by Hg, As, Zn and Pb for the contents of these 4 heavy metals were below the background values despite sites No.4 and No.5 which were slightly contaminated by Pb. Meanwhile, concentrations of Cu in all 12 sites were contaminated in low degree and Cd at a relatively high degree. The contamination degree of these 6 heavy metals could be ranked as the following: $Cd > Cu > Pb > Zn > Hg > As$. Sites No.5 and No.2 were at moderate degree while other sites were at low degree in terms of integrated contamination grade.

Judging from Tab. 5, it was obviously that the effect of biological toxicity for Hg topped all the heavy metals despite its total mean values, which were below the background value in the targeted sea area. Hg was generally viewed as a sort of element with high toxicity and it could pose high biological toxic effect on hydrobios (especially for reparatory system) even the concentration was low ^[22] while Cd was in the last in spite of its high degree of contamination. This could probably be explained that certain sorts of heavy metals like Cd were characterized by particulate property and could easily be transferred by suspended substance into sediments which have biologically decreased the toxicity against hydrobios ^[23-24]. Hence, we suggested that more investigations concerning Hg and Cd should be launched in the targeted sea area.

Tab. 6 Results of I_{geo}

Sites	Indices of I_{geo}					
	Hg	As	Zn	Pb	Cd	Cu
1	-1.601	-2.567	-0.419	-0.122	0.801	0.601
2	-1.595	-2.526	-0.505	-0.150	1.008	0.487
3	-1.682	-2.584	-0.375	-0.234	0.799	0.515
4	-1.575	-2.575	-0.342	0.004	0.875	0.458
5	-1.529	-2.530	-0.315	0.065	1.095	0.714
6	-1.489	-2.521	-0.347	-0.244	0.484	0.316
7	-1.509	-2.521	-0.389	-0.102	0.755	0.470
8	-1.569	-2.560	-0.264	-0.139	0.719	0.490
9	-1.595	-2.560	-0.460	-0.224	0.840	0.420
10	-1.529	-2.472	-0.454	-0.227	0.751	0.468
11	-1.633	-2.517	-0.435	-0.029	0.792	0.596
12	-1.666	-2.483	-0.468	-0.008	0.847	0.506

ISFA was also applied to the assessment in order to verify the results evaluated by I_{geo} . Top 3 sites were No.5, No.4, No.3 which were ranked in descending order (Tab. 7) referring to high degree of sedimentary contamination which was in accordance with the results of I_{geo} and finally verified the results of these 2 evaluation methods as shown in Tab. 6. Given the geographical positions of these 3 sites which were all positioned in the northern part of the targeted sea area (Fig. 1), it facilitated them with high integrated scores and consequently the high degree of contamination was mainly due to assemblages of pollutants from the upper reaches nearby chemical industrial parks and diffusions of construction residuals around reclamation projects. In general, contamination degree for heavy metals in sediments of Yangshan Deepwater Harbor was low.

Tab. 7 Results of ISFA

Sites	5	4	3	6	10	1	8	7	2	9	11	12
Integrated score	1.58	1.25	1.02	0.85	0.55	0.45	0.29	0.20	0.16	-0.02	-0.04	-0.07

3 Conclusions

The conclusions from our study on the source analysis and ecological risk assessment for heavy metals in the sediments of the sea area adjacent to the Yangshan Deepwater Harbor are as follows:

- (1) Concentrations of heavy metals in sediments in the targeted sea area are low and distribute in uniform patterns, with the contents of Hg, Zn, Pb, Cd in autumn higher than those in winter and small fluctuation for As and Cu in seasonal variations.
- (2) Results of FA inferred that the first two components could represent for the major information of all the data sets as the total contribution rate of accumulative variance of the eight factors was 75.710%. F1 contributed 50.229 % to the total contribution rate of accumulative variance and controlled the source of Pb, Cd, Zn and partial organic pollutants which were contributed by the inland industrial and shipping discharge as well as the degradation of organic pollutants in marine environment while F2 contributed 25.480 % to the total contribution rate of accumulative variance and represented the source of heavy metals in sediments from agricultural pollution, cargo shifting and construction debris from reclamation projects for Cu, As and Hg.
- (3) Results of ecological risk assessment for heavy metals demonstrated that the

targeted sea area was at low-and-moderate degree. Hg and Cu were identified as the major eco-risk factors by PEL/TEL Guideline.

(4) The contamination degree of the targeted sea area evaluated by I_{geo} could be ranked as the following: $Cd > Cu > Pb > Zn > Hg > As$. Results of ISFA was in good accordance with I_{geo} and three the most contaminated sites all fall in sites No.5, No.4 and No.3. Generally, the contamination degree for heavy metals in sediments of the Yangshan Deepwater Harbor was low.

Acknowledgments

This work was supported by the Study on the Analysis of the Impacts of Reclamation Engineering on Marine Ecological Environment in Yangshan Deepwater Harbor and Protecting Measures of Shanghai Municipal Science and Technology Commission (No. 12231203402).

References

- [1] Xue J Z, Wang B Q, Zhuang H, et al. Community Structure and Diversity of Fouling Organisms in Yangshan Port [J]. Science & Technology Review, 2011, 29(3): 66 - 70
- [2] Li J Y, Cui Y, Xiao L, et al. Analysis and evaluation on the heavy metal pollution of seawater and marine organisms from Zhoushan sea area and north bank in the Hangzhou Bay [J]. Marine Science Bulletin, 2013, 32(4): 440 - 445.
- [3] Vallee B L, Ulmer D D. Biochemical effects of mercury, cadmium and lead [J]. Annual Review of Biochemistry, 1972, 41: 91 - 128.
- [4] Careiro S, Costa M H, Ramos T B, et al. Assessing heavy metal contamination in Sado Estuary sediment: An index analysis approach [J]. Ecological Indicators, 2005, 5(2): 151 - 169.
- [5] Long E R, Macdonald D D, Smith S L, et al. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments [J]. Environmental Management, 1995, (19): 81 - 97.
- [6] Long E R, Field L J, Macdonald D D. Predicting toxicity in marine sediments with numerical sediment quality guidelines [J]. Environmental Toxicology and Chemistry, 1998, 17(4): 714 - 727.
- [7] Macdonald D D, Carr R S, Calder F D, et al. Development and evaluation of sediment quality guidelines for Florida coastal waters [J]. Ecotoxicology, 1996, (5): 253 - 278.
- [8] Muller G. Index of Geoaccumulation in sediments in Rhine River [J]. Geogournal, 1969, 2: 108 - 118.
- [9] Wang J Y, Ma D Y, Bao Y E, et al. Evaluation on sediment quality in Yellow Sea and East China Sea [J]. Marine Environmental Science, 2003, 29(9): 21 - 24.

- [10] Zhang L X, Jiang X S, Zhao M, et al. Accumulation of heavy metals in surface sediments from the sea region of Yangshan in the Yangtze Estuary with assessment of their potential ecological risk [J]. *Resources and Environment in the Yangtze Basin*, 2003, 22(4): 351 - 356.
- [11] Zhang W T, Dong W. Advanced course of statistical analysis for SPSS [M]. Beijing: Higher Education Press: 2013, 217 - 219.
- [12] Tang Z W, Cheng J L, Yue Y, et al. Accumulations and risks of heavy metals in the sediments from 8 typical lakes in Wuhan, China [J]. *Lake Sciences*, 2009, 21(1): 61 - 68.
- [13] Wang X S, Qin Y. Accumulation and Identification of Heavy Metals in Xuzhou Urban Topsoil [J]. *Journal of China University of Mining & Technology*, 2006, 35(1): 84 - 88.
- [14] Liu X R, Xu Q, Ge X L, et al. Study on configurations of heavy metals in sediments in Miyun Reservoir [J]. *Science in China, Ser.D*, 2005, 35(Sup I): 288 - 295.
- [15] Li Y, Yu Z M, Song X X, et al. Application of Principal Component Analysis (PCA) for the Estimation of Source of Heavy Metal Contamination in Marine Sediments [J]. *Environmental Science*, 2006, 27(1): 137 - 141.
- [16] ZHAO B R. The front change of Changjiang diluted water and its relationship to the river discharge [J]. *Stud. Mar. Sin.*, 1992, 33: 27 - 36.
- [17] Jin W H, Shao X W. Analysis of Water Quality off Zhejiang [J]. *Journal of Zhejiang Ocean University (Nature Science)*, 22(4): 2003, 327 - 331.
- [18] Gan H Y, Zheng Z C, Liang K, et al. Spatial distribution and source of heavy metals in surface sediment from near-shore area of Beihai, Guangxi [J]. *Marine Environmental Science*, 2010, 29(5): 698 - 704.
- [19] Krzysztof L, Danuta W. Application of principal component analysis for the estimation of source of heavy metal contamination in surface sediments from the Rybnik [J]. *Reservoir. Chemosphere*, 2003, 51: 723 - 733.
- [20] Cai L Y. Analysis of the source of heavy metal contamination in surface sediments of Quanzhou Bay based on principal component analysis (PCA) [J]. *Oceanography in Taiwan Strait*, 2010, 29(3): 325 - 331.
- [21] Tong J W, Guan W J, Li J, et al. Assessment on Seawater Quality of a Pier Industrial Area in Startup Time [J]. *Environment and Health*, 2011, 28(1): 55 - 57.
- [22] Chen J S, Zhou J Y. Study on heavy metals in water of China [M]. Beijing: China Environmental Science Press: 1992, 156 - 158.
- [23] Sheng J J, Fan D J, Yang D F, et al. Study on the environmental chemistry of heavy metals in sediments in the waters off Changjiang Estuary and its adjacent area [J]. *Environmental Science*, 2008, 29(9): 2 405 - 2 412.
- [24] Wang X, Qiao S Q, Gao J J, et al. Distribution patterns of heavy metals in surface sediments and environmental quality assessment on the adjacent sea area of Xiaomai Island [J]. *Marine Science Bulletin*, 2013, 32(3): 287 - 295.

洋山深水港区海域秋、冬季沉积物中重金属来源分析及生态风险评价

叶 然, 秦铭俐, 崔永平, 顾红伟, 叶仙森

(国家海洋局宁波海洋环境监测中心站, 浙江 宁波 315012)

摘 要: 通过测定洋山深水港区海域 2010~2013 年 6 个航次秋、冬季沉积物中重金属含量, 分析其时空差异, 结果表明该海域沉积物重金属总体含量较低, 空间分布较为均匀, Hg、Zn、Pb、Cd 含量秋季明显高于冬季, As、Cu 含量的季节性波动较小, 用因子分析法研究该海域重金属来源, 发现陆源工业、船舶航运排污以及有机质降解是研究海域 Pb、Cd、Zn 的主要来源; 农业污染、码头货物装卸残留及建筑垃圾支配着 Cu、As、Hg 的来源。SQG-Q 生态风险评价表明研究海域沉积物中重金属均存在中、低度的生态风险, 秋季的生态风险高于冬季, Hg 和 Cu 是主要生态风险因子; 地累积指数法评价结果显示研究海域基本不受 Hg、As、Zn、Pb 的污染; Cd、Cu 以轻度污染为主, 部分站位属于偏中度污染, 6 种重金属污染程度依次为: Cd>Cu>Pb>Zn>Hg>As。因子综合得分评价表明, 重金属污染相对严重的站位依次为 5 号、4 号及 3 号站位。但总体看来洋山深水港区附近海域沉积物中重金属污染状况属于轻度污染。

关键词: 洋山深水港; 沉积物; 重金属; 生态风险; 污染程度

Study on acid-volatile sulfide (AVS), simultaneously extracted metals (SEM) and its toxic effect on the organism in intertidal sediments of Donghai Island, Zhanjiang

ZHANG Ji-biao, LIU Jia-fei, YAO Jian-hui, YANG Bo, CHEN Chun-liang, SUN Xing-li*

Monitoring Center for Marine Resources and Environments, Guangdong Ocean University, Zhanjiang 524088, Guangdong province, China

Abstract: The content and distribution of acid-volatile sulfide (AVS) and simultaneously extracted metals (SEM) (Cr Cu, Zn, Cd and Pb) were studied in surface sediments collected from the tidal flat of Donghai Island, Zhanjiang. The results indicated that for most stations, the AVS concentration was higher in summer with the average of $0.449 \mu\text{mol/g}$ than that in winter with the average of $1.816 \mu\text{mol/g}$. The AVS contents were higher in southern and northern areas and lower in western and eastern areas. The average content of ΣSEM was between $0.56 \mu\text{mol/g}$ and $4.60 \mu\text{mol/g}$ in summer and between $0.65 \mu\text{mol/g}$ and $2.21 \mu\text{mol/g}$ in winter. The concentration change of single metal was $\text{Zn} > \text{Cr} > \text{Pb} > \text{Cu} > \text{Cd}$ for most stations. The content percentage in ΣSEM was below 1% for Cd and over 70% for Zn. SEM_{Zn} was the key pattern to control the distribution of ΣSEM due to its high concentration percentage. Based on the assessment methods of $(\Sigma\text{SEM}/\text{AVS})$ with $(\Sigma\text{SEM}-\text{AVS})$ and thresholds for metal toxicity to benthic organism, most values of $(\Sigma\text{SEM}-\text{AVS})$ in intertidal flats of Donghai Island were between 0 and 5. The most toxicity region was in Tongminghai area located in the west tidal zone of Donghai Island, and the most toxicity metal was zinc in Tongminghai area in summer. The land-based pollution and the environmental parameters such as sunlight, atmosphere temperature and hydrodynamic characteristics were the main affecting factors on the content level and distribution characteristics of AVS and SEM in intertidal sediments of Donghai Island.

Keywords: AVS; SEM; surface sediments; intertidal flat; Donghai Island

As the transition zone from ocean to land, the exchange flux of matter and energy is much faster in the intertidal region than other sea areas because the intertidal area is alternately exposed to the atmosphere or covered by seawater. Based on the

transportation of suspended substance, the pollutants such as heavy metals, POPs and so on, can be accumulated easily in intertidal sediments through the biological effect, chemical reaction and physical action (Williams et al., 1994; Wang Yong-hong et al., 2002; Srinivasa et al., 2004; Meng Wei et al., 2006). These pollutants are finally harmful to human health through the amplification effect of food chain. The acid-volatile sulfide (AVS) is one of the primary chemical substances controlling the reactivity and availability of heavy metals in the pore water of sediments. The divalent transition metals will not show very serious bio-toxicity because they can react with AVS to form the low toxic and insoluble compound unless the full depletion of AVS (Allen et al., 1993; Ankley et al., 1996; Berry et al., 1996; Di Toro et al., 1992; Ma De-yi et al., 1997). Therefore, the opinion to evaluate the potential ecological effect by using the acid-volatile sulfide (AVS) and simultaneously extracted metals (SEM) is universally accepted.

There is a vast area of tidal flats with resourceful biodiversities in Donghai Island, Zhanjiang. To satisfy the need for new round development of coastal industry in Zhanjiang, especially for the development of steel industry, petrochemical enterprise and paper manufacturing industry, the area of tidal flats in Donghai Island is decreasing day by day due to the tidal-flat occupancy by the sea reclamation, coastal aquaculture, new road building and so on (Li Xiao-min, 2008). And a part of intertidal flats will disappear forever. However, the ecological effect caused by the occupancy of tidal flats is not paid enough attention. Except for a few results reported, until now no systematic research was carried out on the sedimentary characteristics and the quality of ecological environments of tidal flats in Donghai Island. In order to understand deeply the actual situations of sedimentary and ecological environments, the investigations on the content change, distribution characteristics and ecological risk of AVS and SEM were carried out for surface sediments of tidal flats in Donghai Island in this work. Based on the results obtained in this work, it was beneficial to the administrations for reasonable distribution of industry, scientific managements and protective exploitation in Donghai Island.

1 Materials and methods

1.1 Survey region and sampling stations

Donghai Island (20°55' - 21°05'N, 110°11' - 110°31'E), facing straightly the South China Sea, locates in the middle area between the Zhanjiang Bay and Leizhou Bay with a typical tropical climate. It contacts the mainland by Donghai dyke built early in 1950s and a sea-crossing bridge built recently. As the fifth island in China, Donghai Island owns the total land area of 289.49 km², the coastline of 159.48 km and the tidal flat of 401 km² (Zhang

Xi-ran et al.,1987; comprehensive investigation team on marine resources of sea islands in Guangdong Province, 1995; Yang Wen-he, 2000). In the intertidal zone around Donghai Island, it has three sedimentary types including sand, silt and clay. The sediments in the north of Donghai Island, which is named here as region I (region of the Zhanjiang Bay), are mainly clays or silt sands with the tidal-flat width about 0.1 - 2.5 km. The east tidal flat of Donghai Island is about 0.2 - 0.5 km wide and named as region II (region of Longhaitian) with the main sedimentary type of sand. Including all south tidal flats of Donghai Island, the third area (region III: region of the Leizhou Bay) mainly has sands or silts with 25 km long and 1km - 2.5 km wide. The west intertidal region, named as region IV (region of Tongming Sea), almost disappears and only remains rather narrow mud flat due to the occupancy by the coastal aquaculture. The overviews of sedimentary areas around monitoring stations can be seen roughly in Tab. 1.

Eight sampling stations were arranged in intertidal flats based on the topographic features and sedimentary types of Donghai Island. At each station, three sampling spots were set and respectively represented the high tide zone (H), the middle tide zone (M) and the low tide zone (L) (Fig.1). For convenient analyses, eight stations were categorized into four areas from region I to region IV based on the physiographic topography, hydrodynamic environment and service function of sea areas around Donghai Island. Region I belonged to Zhanjiang Bay areas, where station 1 and station 2 were set. Station 3 was set in region II of Longhaitian area. Station 4 - 6 of the Leizhou Bay areas belonged to region III. Station 7 and station 8 were set in region IV of Tongming Sea. Region I was planed to develop coastal industries and region II was used as tourist areas. Region III and region IV were of marine culture area now.

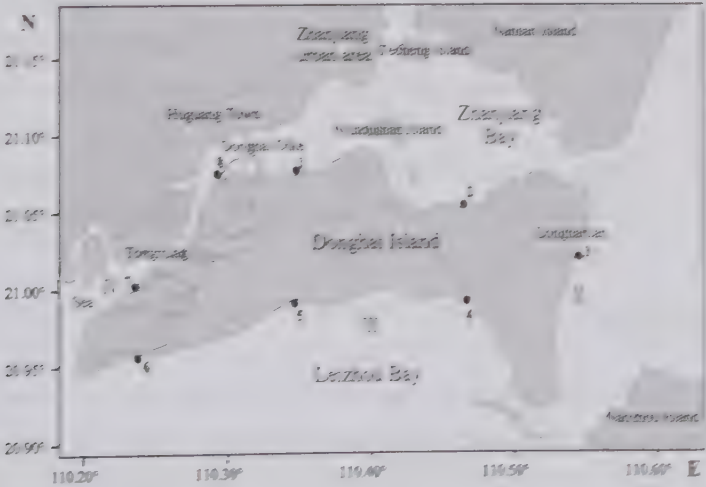


Fig. 1 Distribution of monitoring stations in the tideland of Donghai Island, Zhanjiang

Tab.1 Description of sample stations and sediment features

Station	Overview of sedimentary area
1	Tiaowen village; yellow sand in high tidal region transits gradually into taupe clay in low tidal region.
2	Dongpo village; yellow sand in high tidal region transits gradually into taupe clay in low tidal region; there are a lot of coastal aquaculture farms.
3	Longhaitian holiday area (bathing beach); yellow and coarse sand in high tidal region transits gradually into taupe and fine sand in low tidal region.
4	Jijiao village; fine and yellow sand in high tidal region transits gradually into taupe silt-sand in low tidal region; some mangroves can be found in high tidal areas.
5	Maiqi village; fine and yellow sand in high tidal region transits gradually into taupe silt-sand in low tidal region; some waterweeds can be found in high tidal areas.
6	Xiwan village; grey and fine silt-sand in high tidal region transits gradually into black brown clay in low tidal region; some mangroves can be found in high tidal areas.
7	Dashu village; tidal flats are rather narrow and almost disappear in some zones because of large scale coastal agriculture; grey brown silt can be found in all tidal areas; a submarine outfall from Chenmin Paper Pulp Limited Company is set opposite to this area.
8	Sangang village; tidal flats are rather narrow and nearly disappear in some zones because of large scale coastal agriculture; grey brown silt can be found in all tidal areas;

1.2 Sampling and storage of samples

The sampling, transfer, storage and pretreatment of samples were done based on the specifications for oceanographic survey (GB 12763-2007), and the specifications for marine monitoring (GB 17378-2007). The samples of surface sediments in the intertidal flat of Donghai Island were collected respectively in the daytime of summer from July 14 to 18, 2011 and in the daytime of winter from January 10 to 13, 2012. In the area of 10 m × 10 m, five samples, collected in surface sediments of 0 cm - 3 cm, were mixed uniformly, and the corresponding temperature was measured on site. The mixed sample about 1 kg was put into the plastic bag, and then stored up in the bubble box with ice. The contents of AVS were measured within 24 hours, and the samples of SEM were also prepared at the same time. The remained samples were stored temporarily in the freezing condition for the subsequent testing of other environmental factors.

1.3 Testing of samples

1.3.1 AVS

The content of AVS was measured with the methylene-blue-spectrophotometry. The wet sample of 3.0g was put into the nitrogen-purging meter (Taipute Co. Ltd, LHW-6A) at first, and then (1+2)HCl was dripped in. H₂S produced in the nitrogen-purging meter was

absorbed by the mixed solution of zinc acetate and sodium acetate. Finally, the content of AVS in the mixed solution was measured with the UV spectrophotometer (Shimadzu, UV-2450). To ensure the analysis quality, the standard sample of sulfide (GSB07-1373-2001, the Institute of Standard Sample, MEPC) was used to control the whole testing process, and the recovery rates of standard samples were between 83% and 89%. The water content of wet samples was also measured simultaneously. So the results of AVS were calculated by dry weight in this work.

1.3.2 SEM

After the nitrogen purging was over, the supernatant of 20 mL was sucked up from the residual solution and to centrifuge (Heraeus, D-37520 Osterode). Then the centrifuged supernatant of 5 mL into 25 mL by 2% HNO_3 was diluted. The SEM contents of the dilution were measured by ICP-MS (Agilent Technologies, 7500Cx) in the end.

1.3.3 TOC

After the stored samples were dried up by the freeze drying, the dried samples were then grinded until passing through the screen mesh of 160#. The TOC content of grinded samples was measured by a TOC analyzer (Shimadzu, TOC-V_{CSH}). The average of TOC was calculated based on the testing results of three times, and the final result was shown with the mass fraction of total dry weight.

1.4 Evaluation method and criterion of biological toxic effect

The risk effect of dissolved heavy metals on benthic organisms was evaluated based on the associated method of ($\sum \text{SEM}/\text{AVS}$) and ($\sum \text{SEM}-\text{AVS}$) (Allen et al, 1993; Ankley et al., 1996; Berry et al., 1996; Di Toro et al., 1992). Giving ($\sum \text{SEM}/\text{AVS}$)>1 and ($\sum \text{SEM}-\text{AVS}$)>5, heavy metals in interstitial water were mainly in an ionized state and showed a high toxicity on benthic organisms. Giving ($\sum \text{SEM}/\text{AVS}$)>1 and 5>($\sum \text{SEM}-\text{AVS}$)>0, heavy metals had the middle potential toxicity on benthic organisms. Giving ($\sum \text{SEM}/\text{AVS}$)<1, heavy metals of sediments had no obvious toxicity on benthic organisms because most heavy metals were deposited in sediments by the formation of metal sulfide.

The bio-toxicity effect of single heavy metal on benthic organisms can be understood with the threshold method of biological toxicity. Generally, there is hardly any toxic effect on benthic organisms when single metal content is lower than the threshold effect level (TEL), and the biological toxic effect can appear frequently when single metal content is over the probable effect level (PEL). The biological toxic effect can occur accidentally if single metal content is between TEL and PEL (Grabowski et al., 2001; Lacey et al., 2001).

2 Results and discussion

2.1 The content and distribution of AVS

The content of AVS in sediments was influenced comprehensively by environmental factors such as organic substance, active iron, sulfate, redox conditions, and so on (Van den Hoop et al, 1997; Liu Jing-chun, et al., 2004; David et al., 2005). The content of AVS in intertidal surface sediments of Donghai Island ranged from 0.065 $\mu\text{mol/g}$ to 3.729 $\mu\text{mol/g}$ with the average of 0.449 $\mu\text{mol/g}$ in summer. Except for few stations, the AVS contents at most stations were much higher in winter than in summer, which had a changing range from 0.053 $\mu\text{mol/g}$ to 12.347 $\mu\text{mol/g}$ with the average of 1.816 $\mu\text{mol/g}$. This result in intertidal flats was much inconsistent with that in the sediments always covered by seawater. Two reasons were responsible for the difference of two seasons. Comparatively in winter, the strong sunlight in summer was the primary reason which caused the oxidation of AVS more easily. Thus the high content of AVS could not maintain long-time for surface sediments in intertidal flats. The high air temperature in summer was another cause which made the AVS content lower in summer than that in winter. For the surface sediments of intertidal flats in Donghai Island, the air temperature of summer ranged from 29.1 °C to 33.4 °C with the average of 30.8 °C. However, the air temperature in winter was between 15.1 °C and 17.9 °C and the mean value was just 16.2 °C. Therefore, the H_2S produced in surface sediments would escape easier and more quickly into the atmosphere during the falling of tide due to the high air temperature in summer. Thus the AVS content was universally lower in summer than that in winter for the surface sediments of intertidal flats.

Being influenced by the scattered distribution of mangroves and alternifloras and irregular discharge of coastal agriculture sewages, the AVS contents of surface sediments differentiated obviously with each other in different tidal zones of Donghai Island, and no consistent changing law was found at different stations from high tidal regions to low tidal regions (Fig. 2). It's much different compared with deep sediments in which the AVS content decreased gradually from high tidal regions to low tidal regions (Van den Hoop et al., 1997; Zhang Xiang-shang et al., 2003; David et al., 2005). Due to the tidal effects, the biphasic interface could be formed alternately between the water-sediment interface and the gas-sediment interface, which made surface sediments to be in weak oxidative state or in weak reductive state alternately. Therefore, the content distribution of AVS in different tidal regions had much difference with the results in core sediments of tidal flats or in deep-sea sediments. Meanwhile, the pollutant concentrations were rather high in few tidal regions which had the land-based pollution sources. Thus, the AVS contents of surface sediments in some high tidal zones were much higher than those in other tidal regions,

especially in the regions which had mangroves and alternifloras or coastal agriculture farms (e.g. station 2 and 5 in summer, station 1, 5 and 6 in winter).

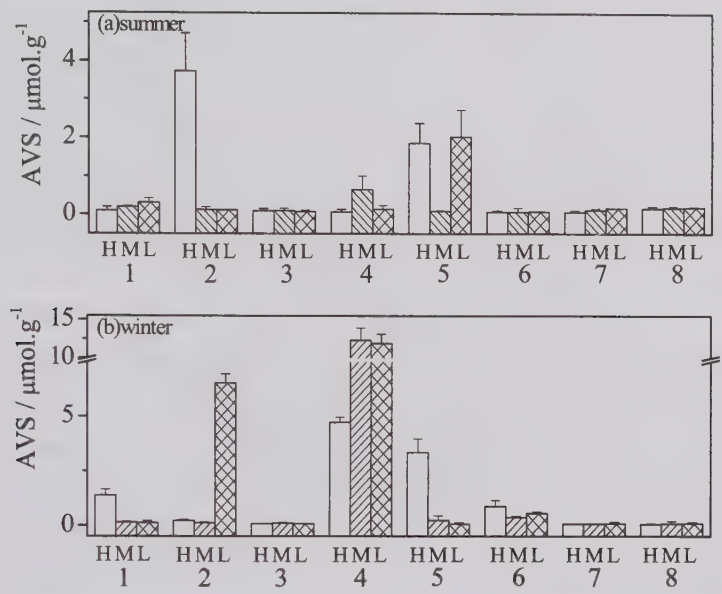


**Fig. 2 AVS content of surface sediments in intertidal zone of Donghai Island
in summer and winter**

(H: high tidal region; M: middle tidal region; L: low tidal region)

As for the regional distribution of the AVS contents, the AVS averages of surface sediments in Donghai Island's intertidal flats were higher in the south and north areas than those in the east and west areas. The corresponding changing order of AVS concentrations was region III (Leizhou Bay areas, $2.193 \mu\text{mol/g}$) > region I (Zhanjiang Bay areas, $1.092 \mu\text{mol/g}$) > region IV (Tongming Sea areas, $0.107 \mu\text{mol/g}$) > region II (Longhaitian areas, $0.085 \mu\text{mol/g}$). It's ascribed to the influence of coastal tidal dynamics and human activities around Donghai Island. For the intertidal sediments of Donghai Island, the sedimentary particles were smaller in the south and north sides of Donghai Island because the coastal tidal currents in those areas were obviously weaker than those in the east (Li Guo-jie et al., 2007). Thus the oxygen permeation became more difficult from atmosphere to sediments, and the sedimentary area was inclined to keep a reduction state more frequently. Therefore more sulfides could be produced in the weak-current areas and the corresponding AVS content was higher there. Due to large-scale coastal agriculture, the west tidal flat of Donghai Island was rather narrow and nearly disappeared in some zones. Even the new sedimentary layer was disturbed frequently by human activities. So the accumulation of sulfide was most difficult in those regions and the AVS contents in west tidal flats of Donghai Island were rather low as a whole.

2.2 The content and distribution of SEM

The simultaneously extracted metals (SEM), which were released easily from sediments by the addition of HCl, included metal sulfides and other metallic forms such as the exchangeable form, the binding speciation of carbonate and Fe-Mn bimetal oxide (Berner, 1984; Van den Hoop et al., 1997; David et al., 2005). The gross contents of simultaneously extracted metals (Σ SEM) extracted the surface sediments of intertidal flats in Donghai Island were illustrated in Tab. 2, Fig. 3 and Fig. 4. On the whole, the Σ SEM in summer was higher than that in winter. The Σ SEM in summer changed from 0.56 $\mu\text{mol/g}$ to 4.60 $\mu\text{mol/g}$, and the maximal value appeared at station 7 and the minimum at station 3. The Σ SEM in winter was between 0.65 $\mu\text{mol/g}$ and 2.21 $\mu\text{mol/g}$, and the maximal value appeared at station 5 and the minimum at station 2 and station 3. From west to east along two sides of Donghai Island, the average of Σ SEM in two seasons decreased gradually, namely the maximum was in region IV (Tongming Sea areas, 2.12 $\mu\text{mol/g}$), then region I (Zhanjiang Bay areas, 1.43 $\mu\text{mol/g}$) and region III (Leizhou Bay areas, 1.14 $\mu\text{mol/g}$). The Σ SEM in region II (Longhaitian areas) was the lowest with the average of 0.70 $\mu\text{mol/g}$.

Tab. 2 Σ SEM of five simultaneously extracted metals in summer and winter/ $\mu\text{mol/g}$

station		1	2	3	4	5	6	7	8
summer	H	1.19	2.61	0.60	1.51	1.67	0.63	2.22	1.87
	M	0.78	3.19	0.63	0.85	1.35	1.19	4.23	4.60
	L	1.90	2.45	0.63	0.93	0.87	0.56	2.55	2.87
	average	1.29	2.75	0.62	1.10	1.30	0.79	3.00	3.12
winter	H	0.65	0.80	0.84	1.03	1.22	0.86	0.83	1.31
	M	1.01	0.68	0.80	1.11	2.21	1.60	1.43	1.39
	L	1.04	0.80	0.66	0.96	1.15	0.79	0.97	1.13
	average	0.90	0.76	0.77	1.03	1.53	1.08	1.08	1.28

(H: high tidal region; M: middle tidal region; L: low tidal region)

As for the contribution of single metal to Σ SEM, the proportion change of single metal was $\text{Zn} > \text{Cr} > \text{Pb} > \text{Cu} > \text{Cd}$ in two seasons. The proportion of SEM_{Zn} in intertidal sediments was the highest which was over 70% for all sampling sites and SEM_{Cr} took the second place. The lowest proportion of SEM_{Cd} was below 1%. From high tidal zone to low tidal zone, it was much different for the contents of single metal at different sites and no similar changing law was found for all stations. For single metal's content in different regions, the content of all five metals was the lowest in region II (the area of station 3). In region III, the elements of higher content were Cr, Cu and Pb. Therein, the Zn content was the maximum

in region IV and then in region I . The Cd content was the minimum at all stations and its regional change was also ruleless. The regional distribution of Σ SEM was determined by the Zn content due to its high ratio in Σ SEM. The high content of Zn in Tongming Sea areas (regionIV) was ascribed to the influence of effluent flow near station 7 discharged by the Chenmin Paper Pulp Limited Company. Due to the multi-factor influences such as shipping business, harbour handling and operating of coastal industries, the Zn content in Zhanjiang areas (region I) was also rather high. As the areas of strong tidal currents and the holiday region, there was no pollutant factory existing around Longhaitian areas (region II), and the content of all metals was the lowest in this area.

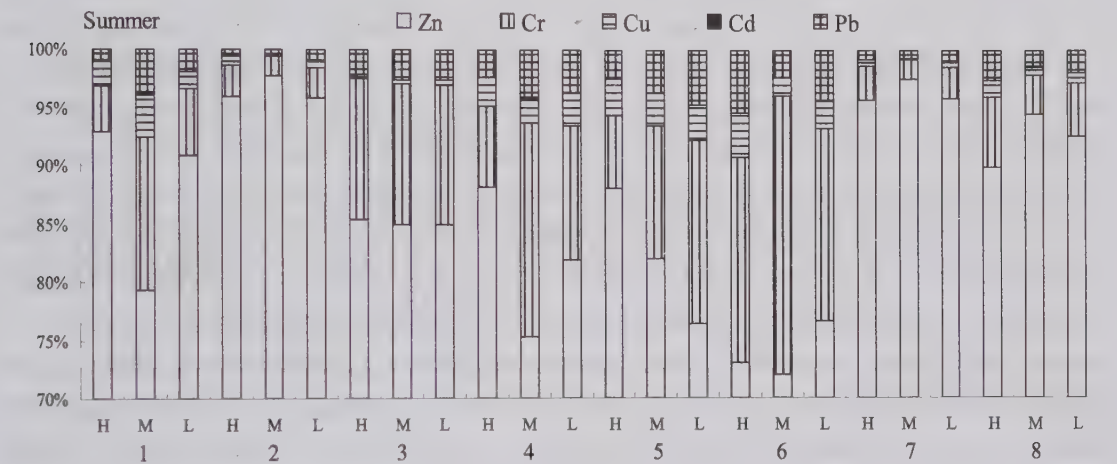


Fig. 3 Contribution of simultaneously extracted metals to Σ SEM (%) in summer

(H: high tidal region; M: middle tidal region; L: low tidal region)

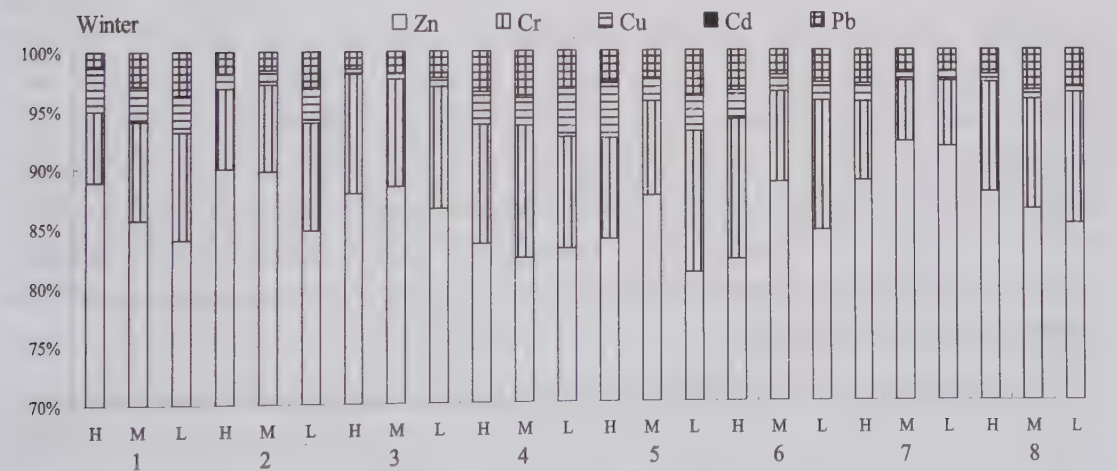


Fig. 4 Contribution simultaneously extracted metals to Σ SEM (%) in winter

(H: high tidal region; M: middle tidal region; L: low tidal region)

2.3 Relativity analysis between AVS and SEM

The simultaneously extracted metals (SEM) were the leaching products from sediments by the reaction with 1mol/L HCl. The leaching products included the dissolved metals of biological effects, the absorbed metals of iron oxide and mono-sulfides which were sensitive to the environmental change, such as bioturbation or mechanical agitation (Berner, 1984; Morse et al., 1987; David et al., 2005; Pu Xiao-qiang et al., 2009). Based on the relativity analysis of the contents between AVS and SEM (Fig. 3), the AVS content showed the positive correlations with total SEM and single SEM. However, the remarkable correlation of AVS was only with Cu ($P < 0.01$), and the relationship of AVS was rather weak with other four metals. This result was also distinct from the remarkable correlation of AVS with SEM for seabed sediments. Because most sample collections were arranged during the daytime due to the actual tide cycle in Donghai Island, AVS and SEM correlated closely with the sampling time and the occurrence frequency of coastal pollution sources. As being exposed directly to the atmosphere, the surface sediments of intertidal flats were in a state of weak oxidation due to the direct oxidations of oxygen and sunlight. Meanwhile, as being influenced by the existence of mangroves and alternifloras and irregular discharge of coastal agriculture sewages, the AVS contents of surface sediments were relatively low and differentiated obviously with each other at different sampling sites, which caused the poor correlation between AVS and Zn, Pb, Cd and Cr. This also meant that the metallic sulfide was not the main speciation for Zn, Pb, Cd and Cr in surface sediments of Donghai Island's intertidal flats.

Different from AVS, the regional distribution of TOC showed the similar changing law with $\sum$ SEM in two seasons. The positive correlation was also found between TOC and $\sum$ SEM or single SEM, and remarkable with Cu, Pb and Zn ($P < 0.05$) (Fig. 3). The result coincided well with the universal dependence relationship of TOC with heavy metals (Liu Jing-chun et al., 2004; David et al., 2005). This meant the organic form of Cu, Pb and Zn was higher in surface sediments of research areas, and there had a strong controllability of TOC on the content of heavy metals. Namely, the organic matter was the important environmental factor for controlling the potential biotoxicity of heavy metals in intertidal sediments of Donghai Island.

As seen from Tab. 3, the content of Zn, Pb and Cu took on the remarkable positive relationship with $\sum$ SEM and the contents of Zn, Pb and Cu also showed the remarkable positive relationship with each other ($P < 0.05$). Although the cadmium sulfide formed easily in seawater, the relativity of Cd was weak with $\sum$ SEM, Zn, Pb and Cu due to its low content below 1.0% of $\sum$ SEM. In addition, because their correlation coefficient was up to 0.989, the

content of Zn showed rather strong positive correlation with $\sum$ SEM ($P<0.01$), which meant that the distribution pattern of $\sum$ SEM was controlled by SEM_{Zn} .

Tab. 3 Spearman correlation matrix of SEM, AVS and TOC

	SEM_{Cr}	SEM_{Cu}	SEM_{Zn}	SEM_{Cd}	SEM_{Pb}	$\sum$ SEM	AVS	TOC
SEM_{Cr}	1.000							
SEM_{Cu}	0.457**	1.000						
SEM_{Zn}	0.131	0.306*	1.000					
SEM_{Cd}	0.344*	0.569**	0.187	1.000				
SEM_{Pb}	0.856**	0.665**	0.359*	0.484**	1.000			
$\sum$ SEM	0.212	0.346*	0.989**	0.208	0.411**	1.000		
AVS	0.106	0.472**	0.051	0.232	0.219	0.076	1.000	
TOC	0.185	0.291*	0.470**	0.281	0.443**	0.443**	0.037	1.000

Note: n=48; *: $P<0.05$; **: $P<0.01$.

2.4 Assessment on the bio-toxicity of heavy metals in intertidal sediments of Donghai Island

In the general assessment of marine environmental quality, the biological effect of heavy metals was exaggerated slightly because a part of heave metals in sediments remained in the residual form which dissolved hardly by using acid digestion. For example, in Fig. 4, the contents of single SEM in intertidal sediments of Donghai Island in summer were rather lower than their total amounts reported in references in similar areas. Except for Zn, even in a strong acid system of HCl, heavy metals which could be dissolved into solution were only a small part of total amount, and most heavy metals were still remained in residual sediments. Thus, it's curtain limitation by using the total amount of heavy metals as the evaluation index to reflect the present quality of marine environments. Therefore, it was recommended by many scholars by using ($\sum$ SEM/AVS) and ($\sum$ SEM-AVS) to assess the biological risk of heavy metals in sediments (Allen et al., 1993; Ankley et al., 1996; Berry et al., 1996; Di Toro et al., 1992). The ($\sum$ SEM-AVS) results of surface sediments in intertidal flats of Donghai Island in summer and winter were listed in Tab. 5.

Also seen from Tab. 5, the averages of ($\sum$ SEM-AVS) in most stations were over 0 and its changing range was from -8.628 to 2.940 in intertidal sediments of Donghai Island. It meant that some dissolved metallic ions were probably permeated into pore water of sediments and caused the potential toxicity to benthic animals because heavy metals' ions in sediments could not be fasten fully by AVS. Thus heavy metals of surface sediments in most intertidal areas of Donghai Island would induce the middle potential toxicity to benthonic organisms. Compared with those in winter, the mean differences of ($\sum$ SEM-AVS)

in all stations were higher in summer, which indicated that more free ions of heavy metals were released from the intertidal sediments of Donghai Island in this season. So the potential bio-toxicity of heavy metals was higher in summer than that in winter. Based on the regional distribution of (Σ SEM-AVS), the areas, where the potential bio-toxicity of heavy metals was relatively low, were located in Zhanjiang Bay's area (region I, station 1 and 2) and Leizhou Bay's area (region III, station 4-6). And the Tongming Sea's area (region IV, station 7 and 8) was in the region where the potential bio-toxicity of heavy metals was relatively high. Because the total amount of SEM was influenced mainly by the high content of zinc due to its proportion over 70% of Σ SEM at different stations, the potential bio-toxicity of heavy metals was induced mainly by zinc for the intertidal sediments of Donghai Island.

Tab. 4 Comparison of SEM of this work with the sum of heavy metals in references/ $\mu\text{mol/g}$

Station	Sampling time	Cu	Zn	Pb	Cd	Cr	Σ	Data type
1	2004.9	0.41	0.77	0.07	0.004	1.23	2.49	Total amount (Guo Xiao-yu et al., 2006)
	2005.8	1.35	5.21	0.11	0.016	-	6.69	Total amount (Zhang Cai-xue et al., 2011)
	2011.7	0.03	0.74	0.03	0.000	0.09	0.90	SEM(in this work)
2	2005.8	0.60	2.34	0.43	0.018	-	3.39	Total amount (Zhang Cai-xue et al., 2011)
	2011.7	0.01	1.87	0.02	0.000	0.05	1.95	SEM(in this work)
3	2005.8	0.32	0.64	0.11	0.013	-	1.08	Total amount (Zhang Cai-xue et al., 2011)
	2011.7	0.00	0.62	0.02	0.000	0.08	0.72	SEM(in this work)

Tab. 5 (Σ SEM-AVS) of surface sediments in the intertidal zone of Donghai Island
in summer and winter

Season	Region	1	2	3	4	5	6	7	8
summer	H	1.096	-1.116	0.507	1.437	-0.190	0.555	2.159	1.706
	M	0.582	3.068	0.524	0.205	1.267	1.122	4.116	4.430
	L	1.589	2.327	0.558	0.784	-1.156	0.484	2.376	2.685
	average	1.089	1.426	0.529	0.808	-0.026	0.720	2.884	2.940
winter	H	-0.733	0.579	0.774	-3.704	-2.124	-0.012	0.766	1.257
	M	0.860	0.567	0.702	-11.241	1.985	1.231	1.373	1.311
	L	0.918	-5.715	0.594	-10.939	1.090	0.228	0.896	1.042
	average	0.348	-1.523	0.690	-8.628	0.317	0.483	1.012	1.203

(H: high tidal region; M: middle tidal region; L: low tidal region)

In order to confirm further whether single metal had the potential biological toxicity or not, the contents of Cr, Cu, Zn, Cd and Pb, dissolved by 1mol/L HCl in intertidal sediments of Donghai Island, were compared with their biological toxicity thresholds of marine sediments (Lacey et al., 2001), and the compared results were illustrated in Tab. 6. For the

sediments of region IV (Tongming Sea areas) in summer, the average content of Zn was up to 2.897 $\mu\text{mol/g}$, which was higher than the threshold effect level (TEL) of 2.199 $\mu\text{mol/g}$ and lower than the probable effect level (PEL) of 4.145 $\mu\text{mol/g}$. This meant that the biological toxicity of Zn could appear accidentally on benthic organisms in intertidal flats of Donghai Island in this season. The contents of other four heavy metals in two seasons were lower than the threshold effect level (TEL) of respective elements, and there was hardly any toxic effect of four heavy metals on benthic organisms in Tongming Sea areas. In addition, in Zhanjiang Bay areas, Longhaitian areas and Leizhou areas (region I -III), the contents of five heavy metals in surface sediments of intertidal flats were all lower than the respective threshold effect level (TEL) in two seasons, which meant the heavy metals of those areas had no biological toxicity on benthic organisms, and their ecological risks were rather lower. In short, for the surface sediments of four intertidal regions in Donghai Island, the region, with stronger biological toxicity, was in Tongming Sea areas (station 7 and 8 there), and the stronger potential bio-toxicity of heavy metals was zinc, also in Tongming Sea areas.

Tab. 6 Contents of single SEM of surface sediments in the intertidal zone of Donghai Island and thresholds for metal toxicity to benthic organism in marine sediments (Lacey et al., 2001) / $\mu\text{mol/g}$

season	region	SEM _{Cr}	SEM _{Cu}	SEM _{Zn}	SEM _{Cd}	SEM _{Pb}
summer	I	0.074	0.022	1.904	0.0001	0.021
	II	0.075	0.003	0.527	0.0000	0.015
	III	0.140	0.028	0.858	0.0001	0.036
	IV	0.100	0.021	2.897	0.0001	0.039
winter	I	0.067	0.022	0.723	0.0001	0.021
	II	0.076	0.004	0.676	0.0000	0.014
	III	0.118	0.032	1.028	0.0001	0.036
	IV	0.094	0.009	1.044	0.0001	0.030
TEL		0.486	0.294	2.199	0.0060	0.329
PEL		1.826	1.699	4.145	0.0374	1.034

3 Conclusions

Based on the investigations on the acid-volatile sulfide (AVS) of surface sediments in intertidal flats of Donghai Island in this work, the average content of AVS was obtained to be 0.449 $\mu\text{mol/g}$ in summer and 1.816 $\mu\text{mol/g}$ in winter, and had a regional distribution that is, the content was higher in south and north areas than that in east and west areas. The total amount of simultaneously extracted metals (ΣSEM) in intertidal sediments ranged from 0.56 $\mu\text{mol/g}$ to 4.60 $\mu\text{mol/g}$ in summer and from 0.65 $\mu\text{mol/g}$ to 2.21 $\mu\text{mol/g}$ in winter, and

the average content of five heavy metals obeyed the following order of $Zn > Cr > Pb > Cu > Cd$. The zinc proportion in $\sum SEM$ was over 70% and the cadmium proportion below 1%, which meant SEM_{Zn} was the main controlling factor for the speciation distribution of $\sum SEM$.

Based on the assessment results associated with the method of $(\sum SEM/AVS)$ and $(\sum SEM-AVS)$ and the threshold method of bio-toxicity, the $(\sum SEM/AVS)$ of surface sediments in most intertidal areas of Donghai Island was changed from 0 to 5. The region of stronger biological toxicity was in Tongming Sea area, and the stronger potential bio-toxicity of heavy metals was zinc in Tongming Sea area. For the surface sediments of intertidal flats in Donghai Island, the content level and regional distribution of AVS and SEM obtained in this work were influenced mainly by the land-based pollution and environmental parameters, such as sunlight, atmosphere temperature and hydrodynamic characteristics around Donghai Island.

Acknowledgements

This study was supported by Marine Public Industry Research of Oceanic Administration, China (2013418038-6).

References

- [1] Allen H E, Fu G, Deng B. Analysis of acid-volatile sulfide (AVS) and simultaneously extracted metals (SEM) for the estimation of potential toxicity in aquatic sediments [J]. *Environmental Toxicology and Chemistry*, 1993, 12(8): 1 441 - 1 453.
- [2] Ankley G T, Di Toro D M, Hansen D J. Technical basis and proposal for deriving sediment quality criteria for metals [J]. *Environmental Toxicology and Chemistry*, 1996, 15(12): 2 056 - 2 066.
- [3] Berner R A. Sedimentary pyrite formation: An update [J]. *Geochimica et Cosmochimica Acta*, 1984, 48(4): 605 - 615.
- [4] Berry W J, Hansen D J, Mahony J D, et al. Predicting the toxicity of metal-spiked laboratory sediments using acid-volatile sulfide and interstitial water normalizations [J]. *Environmental Toxicology and Chemistry*, 1996, 15(12): 2 067 - 2 079.
- [5] David R, John W M. Acid volatile sulfide (AVS) [J]. *Marine Chemistry*, 2005, 97(3-4): 141 - 197.
- [6] Di Toro D M, Mahony J D, Hansen D J. Acid volatile sulfide predicts the acute toxicity of cadmium and nickel in sediments [J]. *Environmental Science and Technology*, 1992, 26(1): 96 - 101.
- [7] Grabowski L A, Houppis J L J, Woods W I, et al. Seasonal bioavailability of sediment-associated heavy metals along the Mississippi river floodplain [J]. *Chemosphere*, 2001, 45: 643 - 651.
- [8] Lacey E M, King J W, Quinn J G, et al. Sediment quality in Burlington Harbor, Lake Champlain, USA [J]. *Water, Air and Soil Pollution*, 2001, 126:97 - 120.

- [9] Morse J W, Cornwell J C. Analysis and distribution of iron sulfide minerals in recent anoxic marine sediments [J]. *Marine Chemistry*, 1987, 22(1): 55 - 69.
- [10] Srinivasa R M, Shaik B, Sravan K, et al. Distribution, enrichment and accumulation of heavy metals in coastal sediments of Alang Sosiya ship scrapping yard, India[J]. *Marine Pollution Bulletin*, 2004, 48(11-12): 1 055 - 1 059.
- [11] Van den Hoop M A G T, Den Hollander H A, Kerdijk H N. Spatial and seasonal variations of acid volatile sulphide (AVS) and simultaneously extracted metals (SEM) in Dutch marine and freshwater sediments [J]. *Chemosphere*, 1997, 35(10): 2 307- 2 316.
- [12] Willams T P, Bubbs J M, Lester J N. Metal accumulation within salt marsh environments: A review [J]. *Marine Pollution Bulletin*, 1994, 28(5): 277 - 290.
- [13] Comprehensive investigation team on marine resources of sea islands in Guangdong Province, Comprehensive investigation reports on marine resources of sea islands in Guangdong Province [M]. Guangzhou: Guangdong Press of Science and Technology, 1995.
- [14] GUO Xiao-yu, HUANG Chang-jiang. Distribution and source of heavy metal elements in sediments of Zhanjiang Harbor [J]. *Journal of Tropical Oceanography*, 2006, 25(5): 91 - 96.
- [15] LI Guo-jie, HU Jian-ping. Numerical simulation of tidal current fields near Donghai Island of Zhanjiang Bay [J]. *Journal of Waterway and Harbor*, 2007, 28(5): 325 - 330.
- [16] LI Xiao-min. Analysis on land use changes and their influential factors in Donghai Island [D]. Hohhot: Inner Mongolia Normal University, 2008.
- [17] LIU Jing-Chun, YAN Chong-Ling, HU Jun. A review on the studies of acid-volatile sulfide in aquatic sediments [J]. *Acta Ecologica Sinica*, 2004, 24(4): 812 - 818.
- [18] MA De-yi, WANG Ju-ying, YAN Qi-lun, et al. Influence of acid volatile sulfide(AVS) on the chemical reactivity of divalent toxic metals in the system of sediment and pore water [J]. *Acta Oceanologica Sinica*, 1997, 19(5): 83 - 90.
- [19] MENG Wei, ZHAI Sheng-jia, QIN Yan-wen, et al. Sources Identification of Heavy Metals in Core Sediments of Bohai Bay [J]. *Marine Science Bulletin*, 2006, 25(1): 37 - 44.
- [20] PU Xiao-qiang, ZHONG Shao-jun, LIU Fei, et al. Geochemical Characters of Reactive Metals in the Estuary Sediments in the Licun Estuary of the Jiaozhou Bay [J]. *Marine Science Bulletin*, 2009, 28(3): 37 - 44.
- [21] WANG Yong-hong, ZHANG Jing, SHEN Huan-ting. Review of Accumulation Features Study of Heavy Metal in Sediment of Tidal Flat [J]. *Advance in Earthsciences*, 2002, 17(1):69 - 77.
- [22] YANG Wen-he. Sea Islands of China [M]. Beijing: China Ocean Press, 2000.
- [23] ZHANG Cai-xue, SUN Xing-li, CHEN Chun-liang. Heavy Metals in Seawater, Surface Sediment and Shellfishes in Tideland of Zhanjiang Harbor [J]. *Journal of Guangdong Ocean University*, 2011, 31(1): 67 - 72.
- [24] ZHANG Xi-ran, LUO Xuan. The Characteristics of Tidal Flat Soil of Zhanjiang Harbour and Leizhou Bay [J]. *Tropical Geography*, 1987, 7(2):128-136.

- [25] ZHANG Xiang-shang, ZHANG Long-jun, WU Yu-ke. Study of Acid Volatile Sulfide (AVS) and Simultaneously Extracted Metals (SEM) in Clayey Tidal Zone Sediments [J]. Journal Of Ocean University of Qingdao, 2003, 33(3): 420 - 424.

湛江东海岛潮间带沉积物硫化物(AVS)和重金属(SEM)及其生物毒效性评估

张际标, 刘加飞, 姚兼辉, 杨波, 陈春亮, 孙省利*

(广东海洋大学海洋资源与环境监测中心, 广东 湛江 524088)

摘要: 对湛江东海岛潮间带表层沉积物中酸可挥发性硫化物(AVS)和同步提取重金属(SEM)的含量及其分布进行了研究。研究表明, 东海岛潮间带表层沉积物中 AVS 含量夏季平均为 $0.449 \mu\text{mol/g}$, 冬季为 $1.816 \mu\text{mol/g}$, 大多数站位 AVS 含量冬季高于夏季; AVS 平均含量总体呈南、北区较高, 东、西区较低的区域分布规律。潮区沉积物可提取重金属 SEM 总量夏季在 $0.56 \mu\text{mol/g} \sim 4.60 \mu\text{mol/g}$ 之间, 冬季处于 $0.65 \mu\text{mol/g} \sim 2.21 \mu\text{mol/g}$ 之间; 各重金属平均含量大小为 $\text{Zn} > \text{Cr} > \text{Pb} > \text{Cu} > \text{Cd}$, 其中 Cd 含量占 SEM 总量不到 1%, Zn 含量则在 70% 以上, SEMZn 是控制着 SEM 分布的主要模式。联合利用 ($\sum \text{SEM}/\text{AVS}$) 与 ($\sum \text{SEM}-\text{AVS}$) 法和生物毒性阈值法综合评估重金属对沉积环境的影响, 东海岛潮间带大部分区域沉积物中 ($\sum \text{SEM}-\text{AVS}$) 处于 0 ~ 5 之间, 重金属潜在生物毒性较强的区域为通明海区(7 号站和 8 号站所在), 具有较强潜在生物毒性的重金属为夏季通明海区的 Zn。

关键词: AVS; SEM; 表层沉积物; 潮间带; 东海岛

Research on the rationality of artificial reef layout of Dashentang

WANG Hong, GUO Biao, GAO Yan, DAI Yuan-yuan, MA Chao

Tianjin Bohai Sea Fisherise Research Institute, Bohai Sea Fisheries Research Center, Chinese Academy of Fishery Sciences, Tianjin 300457, China

Abstract: By the means of technology of CFD (Computational Fluid Dynamics), this research has studied the surrounding flow field effect of different combination of artificial reefs. In the study, four kinds of configurations are used to simulate numerically, and these are "444" three columns, "464" three columns, "12345" five triangles and the "34543" five column regular hexagon. The result shows that the combination of artificial reefs of Dashentang can play a good role in regulating the reefs.

Keywords: CFD; artificial reefs; layout

An artificial reef (including fish reefs, algal reefs and shellfish reefs) is a man-made, underwater structure, typically built for the purpose of promoting marine life community structure and the habitat environment, providing new habitat for the settlement and shelter for eggs, larvae, juveniles, favoring recruitment, recovering of quality of environment and fishery resources. Recently, the coastal fishery industrial structure adjustment is undergoing. The artificial reef has been developed in many coastal cities. It's widely accredited that the construction of artificial reef is a significant measure to improve marine ecological environment, recover and promote fishery resources, protect biodiversity and promote marine economy development^[1, 2]. The rationality of artificial reef layout is the key problem of the construction of the artificial reefs. In this paper, the technology of CFD (Computational Fluid Dynamics) is used to simulate the flow field that around the area of artificial reefs under the condition of different combinations.

The main methods of studying the fluid flow problems are CFD numerical simulation field measurement, wind tunnel water tank, et al. Compared with field measurement and wind tunnel water tank experiment, CFD numerical simulation has become more and more popular because of its small input and constant improvement of the simulation precision. CFD has been widely used, and the advanced commercial CFD software has been widely adopted. They are FLUENT, CFX, Phoenix and so on.

Scholars have studied the flow field around the artificial reefs by the method of

numerical simulation^[3-6].and studied the effect of the square layout spacing of artificial reefs on the flow field around^[7].The article simulates and studies the flow field effect of the combination of artificial reefs, which is based on the CFD simulation technology, and compares the rationality of artificial reef layout of Dashentang.

1 Profile of the artificial reef layout of Dashentang

Bohai Sea is China's largest shallow inland sea, spanning 550 kilometers from north to south, 346 kilometers wide, and it has 3 700 kilometers coastline, and an area of about 7.7 square kilometers, but Bohai strait is only 106 kilometers wide, and has a typical big belly with a small mouth. Its average depth is 18 meters, and the maximum depth is 86 meters, and it is a nearly closed shallow sea which goes deep into the mainland. The artificial reefs' construction site is in Dashentang , a special protection area of Bohai bay ,in the area bounded by the following four points of connectivity:

A:	117°58'10"E	39°6'32"N
B:	117°58'35"E	39°6'32"N
C:	117°58'35"E	39°6'12"N
D:	117°58'10"E	39°6'12"N'

2 Combinations of the reef configuration

The reef layout which is studied amounts to four kinds, respectively shown in Fig. 1 to Fig. 4. In addition to the configuration shown in Fig. 2, the flow direction is from the southeast to the northwest, and the rest are all from north to south.

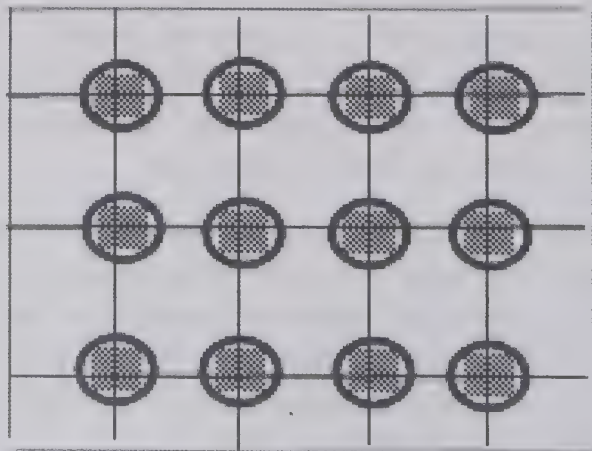


Fig. 1 Configuration one

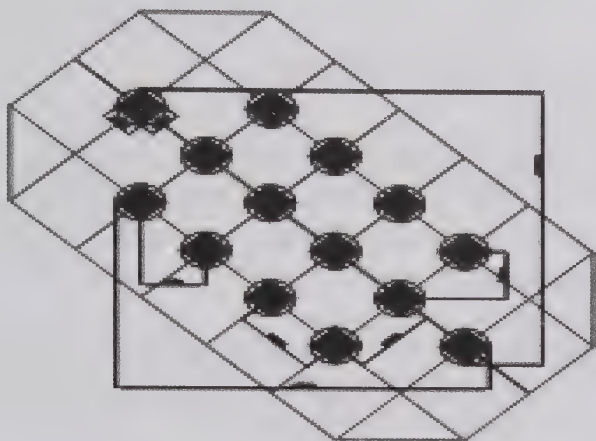


Fig. 2 Configuration two

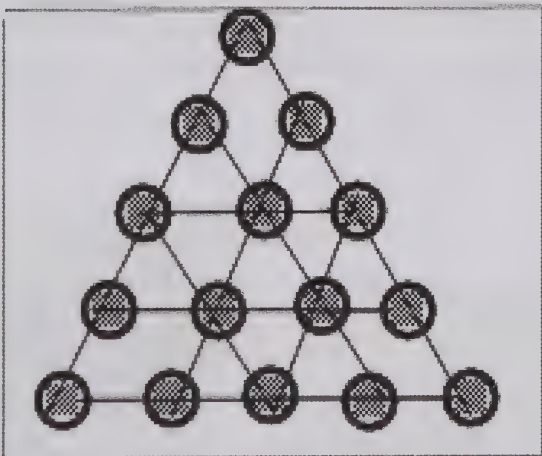


Fig. 3 Configuration three

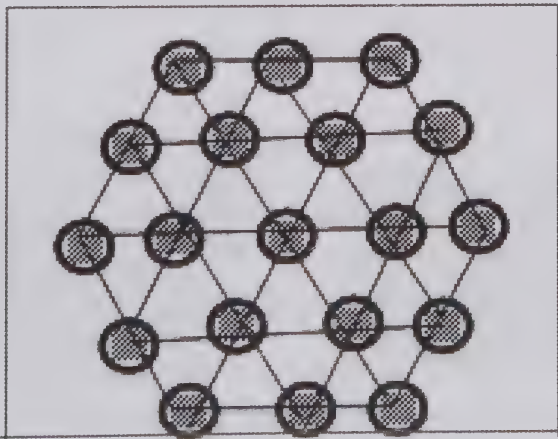


Fig. 4 Configuration four

3 The CFD and calculation conditions

According to the results of numerical simulation of flow field in the Bohai Bay, we simulate the flow field effect of the Dashentang artificial reefs by using CFD software Fluent, and through the analysis, we get the scientific and reasonable configuration mode that fits the artificial reefs of Dashentang.

Different reef layout can also affect the influence range of eddy currents, and the scale of reefs is 20 m long, 20 meters wide and 1.5 m high, among the four groups of reef configuration, the distance between the reef groups is 100 meters, to calculate the changed size of reef area along with the configuration of reef number and position, because of the symmetry of the four reefs' geometrical arrangements and their flow fields. The calculation area shown in Fig. 1 to Fig. 4 is half of all the area, for example, the calculation area of configuration one is shown in Fig. 5. The entrance current velocity of different arrangements of reef layout is the actual sea state velocity, 0.5 m/s.

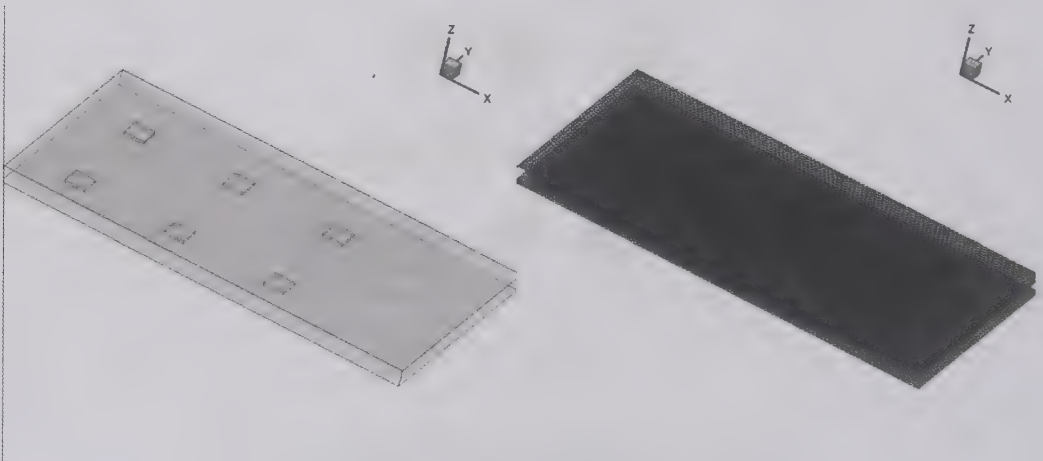


Fig. 5 Calculation area of configuration one

4 The results of numerical simulation and analysis

4.1 Flow field effect of the four reef combinations

Fig. 6a-6d are the contour maps of the whole calculation area level sections' flow velocity, which are under the condition of four different kinds of reef configurations. As shown configuration one is "444" three column layout and the former reefs have certain flow effect on the back ones. Criterion of the back vortex area is 80% of the inflow velocity,

so the volume of the back reefs' back vortex area is bigger.

As the figure shows, configuration two is "464" three column layout, and the former reefs have certain flow effect on the back ones. The number of middle reefs is bigger, and its slow flow effect is the most obvious. The greater the eddy zone is, the bigger the volume of the back reefs' back vortex area is.

As shown in configuration three, it is "12345" five triangle layout, and the former reefs have certain flow effect on the back ones. However, because of the alternative arrangement, the position of the reefs is far from the two configurations above on the flow direction, and the accumulated effect of slow flow is not obvious.

Configuration four is "34543" five column regular hexagon layout, and the former reefs have certain flow effect on the back ones. Similarly, because of the alternative arrangement, the position of the reefs is far from the two configurations above on the flow direction ,and the accumulated effect of slow flow is not obvious, which is similar to configuration three.

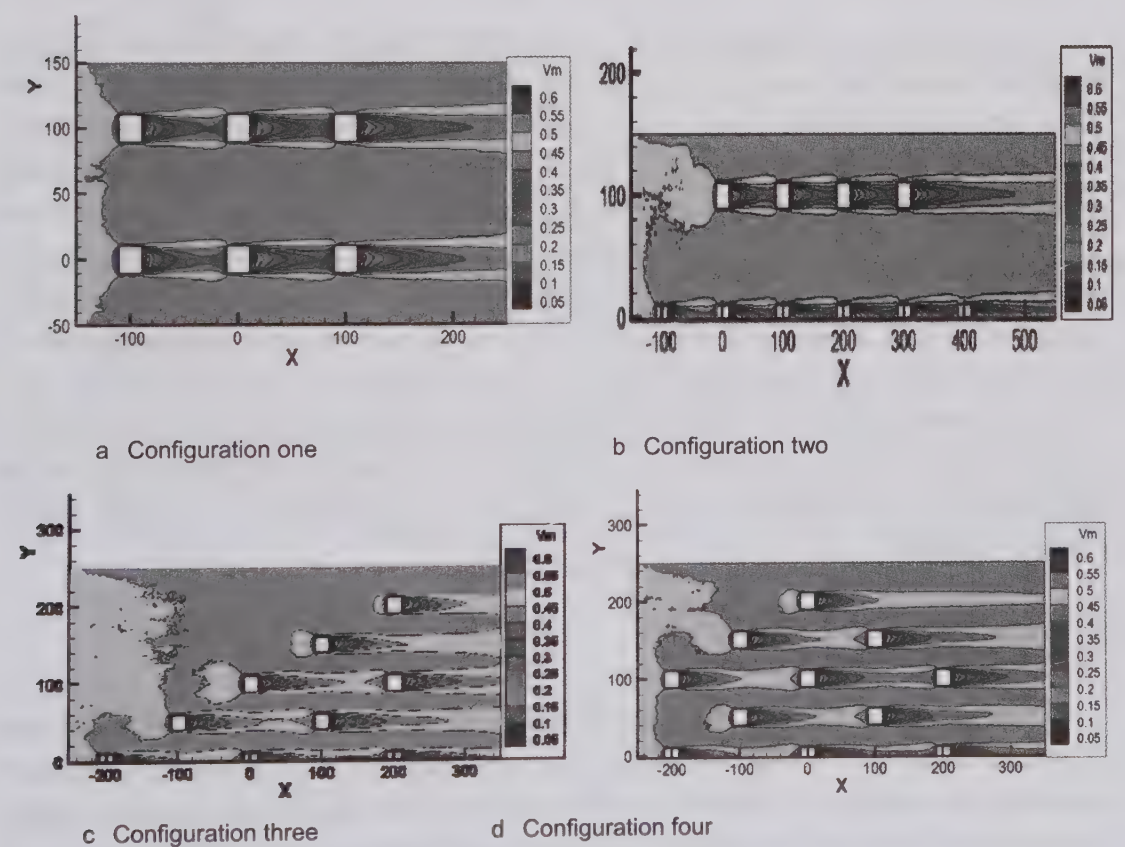


Fig. 6 Contour maps of the whole calculation area level sections' flow velocity

4.2 Results and analysis

Using Tecplot software to calculate the volume of upwelling and back eddy current, the flow field effect of all kinds of reefs arrangement is shown in Tab. 1.

Tab. 1 Volume of upwelling and back eddy current

Regions	The volume of upwelling / m ³	The volume of back eddy current / m ³	Number of artificial reefs	The volume of every individual reefs' upwelling / m ³	The volume of every individual reefs' back eddy current / m ³
configuration one	3151.02	12978.40	6	525.17	2163.07
configuration two	3487.92	17009.72	7	498.27	2429.96
configuration three	3944.90	13284.71	7.5	525.99	1771.29
configuration four	5007.52	16988.68	9.5	527.11	1788.28

By comparing the results above, we can know that, the flow field effect and the difference between each one is small, which is perpendicular to the flow direction, because of the distance between the reefs is far, so the volume of every individual reef's upwelling area is small. And along the coming flow direction, the effect between reefs is greatly influenced by the configuration mode. From the geometric configuration, the distance from front to back in configuration 1 and 2 is further than that in configuration 3 and 4,so it has a great effect on the volume of back eddy current, so the volume of back eddy current in configuration 1 and 2 is larger than that in configuration 3 and 4. Comparing configuration 1 with configuration 2, configuration 2 has a greater influence on the area of back eddy current, because of its larger number of reef layout, so the volume of back eddy current in configuration 2 is larger than that in configuration 1. From the calculation results, the average volume of individual reef's back eddy current in configuration 2 is the maximum, that is 2 429.96 m³.

5 Conclusion

This paper simulates the movement rule around the artificial reefs under the condition of four combinations, which is based on CFD numerical simulation technology. The result shows that the volumes of upwelling and back eddy current are different between different configurations. Generally speaking, the difference of upwelling area's volumes is not big. The average volume of individual reef's back eddy current in configuration two is the

maximum, 2429.96 m³, and its flow effect is the largest. The reef combination of Dashentang, a special protection area of the Bohai Bay, which is used to construct artificial reefs, is the configuration two. The result of this paper shows that the combination of artificial reefs of Dashentang can play a good role in regulating the reefs, and the construction of artificial reefs is comparatively reasonable.

Acknowledgements

This research is financially supported by the Key Laboratory of Marine Oil Spill Identification and Damage Assessment Technology, State Oceanic Administration (201214), Key Laboratory of Pollution Processes and Environmental Criteria (Nankai University), Ministry of Education (KL-PPEC-2013-09).

References

- [1] Seaman W J. Artificial reef evaluation: with application to natural marine habitats [M]. USA: CRC press, 2000, 5 - 6.
- [2] Yang Lin, Liu Tongyu, Huang Rukan. Origin and History of Artificial Fish Reef [M]. GuangZhou: Guangdong Science and Technology Publishing House, 2005.
- [3] LIU Hong-sheng, MA Xiang, ZHANG Shou-yu, et al. Validation and comparison between wind tunnel experiments and numerical simulation of flow field around artificial reefs [J]. Journal of Fishery Sciences of China, 2009, (3): 365 - 371.
- [4] HUANG Yuandong, ZHAO Shufu, JIANG Jianwei, et al. Study on numerical simulation of water flow past a porous square artificial reef [J]. Journal of Water Resources and Water Engineering, 2012, 23(5): 15 - 18.
- [5] HUANG Yuandong, JIANG Jianwei, ZHAO Shufu. Study on numerical model of water flows past a square artificial reef [J]. Journal of Water Resources and Water Engineering, 2012, 23(3): 1 - 3.
- [6] CUI Yong, GUAN Chang-tao, WAN Rong, et al. Research and Numerical Simulation on Features of Flow Field Around Artificial Reefs [J]. Journal of System Simulation, 2009, 21(23): 7 393 - 7 396.
- [7] Numerical Simulation on Influence of Disposal Space on Effects of Flow Field Around Artificial Reefs [J]. Transactions of Oceanology and Limnology, 2011(2): 59 - 65.

大神堂人工鱼礁礁区布局的合理性研究

王 宏，郭 彪，高 燕，戴媛媛，马 超

(天津渤海水产研究所 中国水产科学院渤海水产研究中心, 天津 300457)

摘 要: 以 CFD(计算流体动力学) 技术为手段, 研究了不同配置组合人工鱼礁区周围的流场效应。研究中采用了 四种配置组合, 分别为 “444” 三列, “464” 三列, “12345” 五列三角形, “34543” 五列正六边形进行数值模拟, 结果说明大神堂人工鱼礁礁区的礁群配置组合能够较好地发挥礁区的调控作用。

关键词: CFD; 人工鱼礁; 礁区布局

海 洋 通 报 (英 文 版)

HAIYANG TONGBAO

2014 年 5 月 第 16 卷 第 1 期

目 次

历年影响广西沿海的热带气旋及其灾害成因分析 陈 波 等 (14)

天津沿海风暴潮灾害近 20 年统计及其成因分析 李希彬 等 (24)

基于特征区域统计的多光谱遥感影像海岛瞬时岸线提取 王 丰 等 (37)

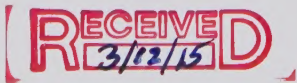
海洋功能区划评估研究与实践 黄南艳 等 (50)

因子分析在海河流域石油类污染综合评价中的应用 戴媛媛 等 (58)

洋山深水港区海域秋、冬季沉积物中重金属来源分析及生态风险评价 叶 然 等 (72)

湛江东海岛潮间带沉积物硫化物 (AVS) 和重金属 (SEM) 及其生物毒郊性评估
..... 张际标 等 (88)

大神堂人工鱼礁礁区布局的合理性研究 王 宏 等 (96)



Marine Science Bulletin

Marine Science Bulletin publishes papers on marine science and technology including physical oceanography, chemical oceanography, marine biology, marine geology, environmental oceanography, estuarine & coastal sciences, marine technology, digital ocean, coastal zone management, ocean engineering, marine economics, etc., and aims to promote international academic exchange.

Editor-in-Chief: XU Sheng (徐 胜)

Associate Editor-in-Chief: LI Dong-xu (李东旭) XUE Hui-feng (薛惠芬)

Executive Editor: QIU Wen-jing (邱文静) DONG Yi (董 艺) LI Xiao-guang (李晓光)

LI Xue (李 雪) YANG Rui (杨 瑞) YUAN Ze-yi (袁泽轶)

English proofed by: WANG Qi (王 琦)

Semi-annually (started in 1999, sum 31)

Publication date: May 15th and Oct. 15th

Marine Science Bulletin

(Vol. 16, No. 1, May 2014)

Responsible Institution:

State Oceanic Administration of China

Sponsored by:

National Marine Data and Information Service

Edited by:

Office of Marine Science Bulletin (English edition)

Printed by:

Printery of National Marine Data and Information Service

Published by:

Office of Marine Science Bulletin (English edition)

E-mail: msb@mail.nmdis.gov.cn

Tel: (022) 24011287

Address: 93 Liuwei Rd., Hedong District, Tianjin
300171, China

ISSN1000-9620

CN12-1271/N

Price: \$ 30.00 / ¥ 40.00 Per year

ISSN 1000-9620



9 771000 962001

